The Book of POPULAR SCIENCE

The Wonders of Modern Discovery
The Triumphs of Inventive Genius
The Story of all Created Things and
the World They Live In

VOLUME VI

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THE MELANCHOLY GAZE OF THE SUICIDE

ANTINOUS, THE FAVORITE ATTENDANT OF THE EMPEROR HADRIAN

FRONTISPIECE VOLUME VI

The Book of
POPULAR SCIENCE

The Wonders of Modern Discovery
The Triumphs of Inventive Genius
The Story of all Created Things and
the World They Live In

EDITED by a group of distinguished scientists including members of the faculties of the Massachusetts Institute of Technology, Cornell, Harvard and Leland Stanford Universities, The Universities of Iowa, Michigan, Rochester, Tokyo, Toronto and Wisconsin, Catholic University of America, Rutgers, Vassar and Woodstock Colleges, New York State College of Agriculture and the College of Physicians and Surgeons

VOLUME
VI

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THE SUN THE LORD OF LIFE

The Mighty Power of our Ruling Star Dispensed Throughout Space by its Radiant Energy

WHAT WE THINK WE KNOW OF THE SUN

CERTAINLY astronomy has scarcely any record of greater achievement than the discovery that the sun is one of the stars. That discovery gives us a new conception of the universe. Further, the systematic comparison of the sun with the stars, notably as regards the quality of their light, teaches us far more fundamental facts about the universe than separate study of either could afford. We have everything to gain from the study of the sun as a star — as that particular specimen of the stars which is under our close observation, and from which we can learn, in large degree, what are the other stars, whose remoteness is so great. The sun is more than ninety millions of miles away, no doubt, but the *next* nearest star is at least twenty millions of millions of miles away, so that, relatively to any other star, the sun is under our immediate watchfulness. And the advances of spectroscopy, the analysis of light, are enabling us to classify the stars, and group the sun with certain others which conform to the particular type, and perhaps to the particular stage of evolution, which the sun exhibits. All this is the study of the sun with reference to the stars, and the new astronomy finds therein a most fertile and almost boundless field of inquiry.

But, after all, the sun is *our* star, and we astronomers are human beings, born upon a satellite of the sun. Therefore the study of the sun in relation to our earth must certainly precede — in importance, as it also has done in the history of astronomy — the study of the sun in relation to the stars. We look at Sirius, or at the nebula in Andromeda, and they interest us intensely, and repay our study, but we cannot doubt that if Sirius, or any other individual star but one, or any nebula whatever, were at this instant to cease to be, the life of man would be wholly unaffected. They produce neither life nor death, health nor sickness; their movements and positions have no prophecies or warnings for the lives of men; their light suffices for us to see them by, and in some degree to study them by; it stimulates and illumines our minds but it scarcely serves to warm or illumine our bodies, nor does it in any way affect our earth as a habitation for us. Our interest in them is therefore almost wholly theoretical, detached, academic, impersonal, of today, and markedly contrasts with the feelings which animated certain of our forefathers who were devoted to astrology and who studied the stars in order to know what would happen to them or their credulous consultants tomorrow.

The star we call the sun, however, sustains our lives, causes death, drought, harvest, health and illness; its changes affect the magnetic needles of our compasses; and it would seem that the cycles of its spots and storms can be connected with climatic variations and even with fluctuations in the wheat supply and the growth of trees. Whatever the historical origin of the relation between the sun and ourselves, no matter whether it be our big brother, no matter whether our planet was originally captured by the sun, or was derived from a detached portion of the sun's exterior, it is certain that the existing relations between the sun and the earth are profound, numerous, indissoluble, and that they, beyond all other facts of the material world, condition the physical life of man.

We have used the word "numerous", and must justify it. The older astronomy centered its interest, inevitably, in the gravitational relation between the earth and the sun. After all, not many generations have passed since man discovered that his earth revolves round the sun, and that this revolution is controlled by gravitation. That single fact can be, and has been, extended, so as to build what has often been called a gravitational astronomy, and there is no end to the investigations which it must pursue. If we are about to insist that, in a sense, that is only the beginning of the study of relations between the sun and the earth, we must not underrate its importance. On the contrary, let us acknowledge that the extensions of the purely gravitational astronomy of sun and earth still promise new things, not least as regards meteorology.

How the gravitational power of the earth raises tides on the sun

Let us briefly note, then, what this single gravitational relation involves.. First, it explains and conditions the earth's annual revolution in its orbit. But that is only the beginning of the problem, for gravitation does not act between the sun as a whole and the earth as a whole. The law of gravitation asserts that every particle of matter in the universe attracts every other particle with a certain force. All the sun is thus pulling on every individual atom that composes the earth, and *vice versa*.

No matter, then, what the sun and the earth are made of, their gravitational action on each other must, in many details, be very different from that which astronomers have, for convenience of calculation, so generally assumed — the action of two imaginary points pulling on each other at a certain distance and with a certain force. The sun and the earth react gravitationally upon each other's parts.

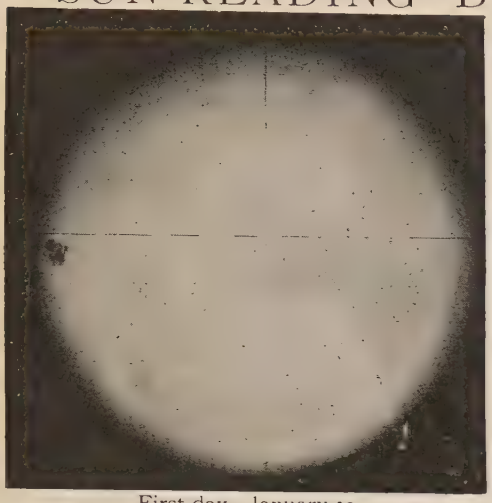
Up to a point there can be no doubt of this, for we know that the sun raises daily tides upon the oceans of the earth, as they are rotated in succession towards and away from the pull of the sun. And we already know that these sun-raised earth-tides, as studied especially by Sir George Darwin, are bound to produce in the movement of the earth effects which, though less extensive than his assumptions led him to estimate, may become notable in the course of ages. But as Galileo first found, when his telescope revealed the sun-spots and their passage across the solar disc, the sun also rotates upon its own axis, just as the earth does, and, as we know, in the same direction. But this must mean that the earth raises tides on the sun; and these earth-raised sun-tides are special consequences of the gravitational relation between earth and sun, which will have large results for the solar system as a whole some day.

Many forget that gravitation is always and necessarily mutual. When the apple falls to the earth, the whole earth also rises to the apple, in a tiny but inevitable degree determined by the relative masses of the apple and the earth; and, just similarly, while the sun attracts the earth, so also does the earth attract the sun. If the sun, while under this constant gravitational influence of the earth, is rotating, it follows that successive portions of its surface will each in turn come nearer to the earth, will be more affected by its pull, and thus tides will be raised upon the sun, just as the sun raises tides upon the oceans of the earth which are forever rotating under its pull.

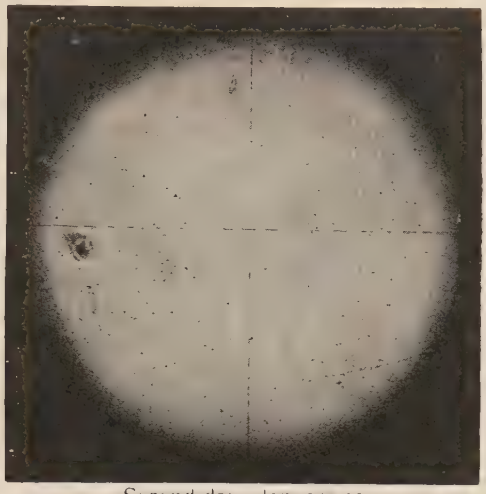
The unrealized fact that tides may be gaseous or solid as well as liquid

The sun has no water of any kind, much less water so cool as to be liquid and form oceans. But that matters not at all. It is only our conventional thought which assumes that tides must always be in liquids. Tides depend upon gravitation, and all matter exercises and is exercised by gravitation. Hence, where liquid matter comes under tidal action, as in our oceans, we have liquid tides, but where gaseous matter is concerned, as in the atmosphere of the sun and the atmosphere of the earth, we have gaseous tides; and it has lately been possible to demonstrate the existence of the solid tides, in the crust of the earth, which are raised by the sun and the moon, and which astronomers were bound to expect long before instruments delicate enough to detect them could be devised.

SUN-READING BY PHOTOGRAPHY



First day— January 30



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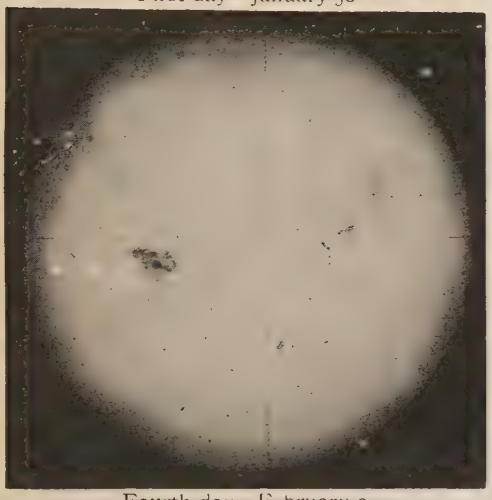

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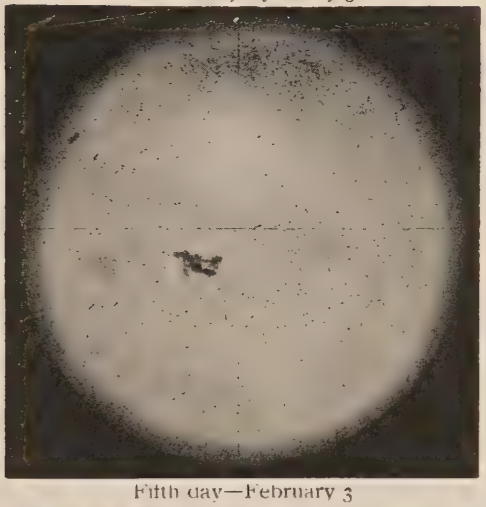

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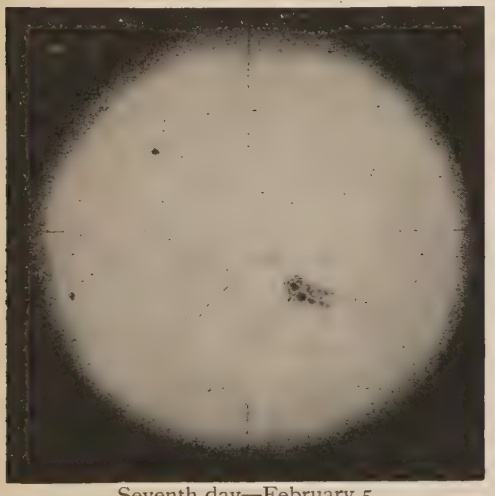
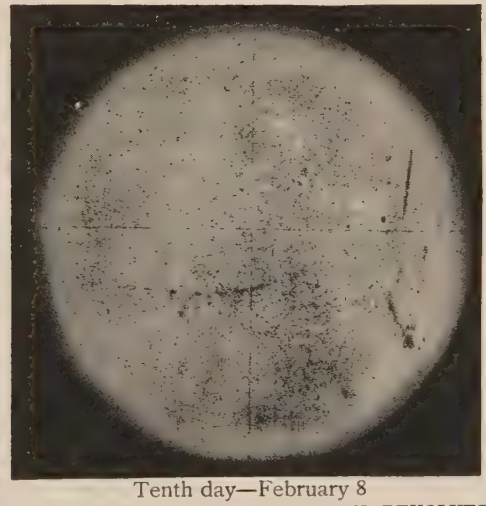


Seventh day—February 5



Tenth day—February 8

TEN DAYS' PHOTOGRAPHS OF SUN-SPOTS IN 1905, SHOWING THAT THE SUN REVOLVES

These beautiful photographs, taken at the Royal Observatory, Greenwich, are reproduced by permission of the Astronomer Royal.

Cities and continents raised and dropped several inches by attraction of the sun

Thus, every one of our great cities is ceaselessly being lifted bodily upwards, and then dropped again, a distance of several inches, by the gravitational action of the moon, and to a less degree by that of the sun, as the earth in its rotation brings the city under their respective attractions; the amount by which the earth is raised in any locality depends both on the latitude of the place and upon the position of the tide-raising body. The maximum range of the earth tide produced by the moon for, say, a place in the latitude of New York or Pekin is a little over twelve inches, while the maximum tide produced by the sun is a little over four inches: hence when the two tide-raising forces have their maximum effect simultaneously these cities are lifted and lowered about seventeen inches. These tidal, rhythmical deformations of the crust of the earth must in due course affect the rotation of the earth and the destiny of the entire solar system itself.

We have alluded to gaseous tides, the atmospheric tides raised on the sun by the earth, and raised on the earth by the sun and the moon. Here is a subject which is practically new, and about which little can yet be said. But there can be no doubt that it must have a special bearing on some of the problems which meteorology has so long been trying in vain to solve. The questions of climate and weather do not here concern us, but we are bound to observe that the general gravitational influence of the sun upon the earth extends in such ways as these to the most intimate and seemingly local details of the immediate environment of man.

What would happen if, at any given instant, this invisible bond between sun and earth should cease to exist? Following Newton's first law of motion, the earth would immediately leave its elliptical orbit at a tangent according to what used to be called "centrifugal force," and would move further and further from the sun. It would cross the orbits of the outer planets, and, assuming that it escaped their influence, would soon pass into outer space.

Only as captives of the sun can we be free to live

The conditions of the earth's surface would change in just the opposite direction to that described by the great American astronomer, the late Professor Simon Newcomb, in a popular account of the approach of some imaginary star to the solar system, on its way to a collision with the sun. In that case the earth's surface would become hotter, with results soon fatal to mankind and to all forms of life. But if the gravitational bond between the earth and the sun were annulled, the earth, leaving the sun, would become steadily cooler, and the results would be just as disastrous. Marvelously adaptable as terrestrial life is to the conditions of the earth's surface, it could not survive any such changes as would follow if the earth left its orbit. This is the answer to the rather fanciful speculation put forward some years ago by Maeterlinck, that within a few centuries man might be able to control gravitation, and take his planet where he pleased. The best place for our planet is where it is, if we wish to survive upon it; and hence the force of gravitation, which swings the earth in its orbit round the sun, conditions our existence. Only captive to the sun are we free to live.

We have already seen that the most advanced thought of our time is inclining to regard gravitation as electrical in its nature. However that may be, it is certain that the sun is a center of tremendous electrical force, which is of the utmost importance for our planet. Whether or not the force is akin to gravitation, as may be, whether or not it is conveyed through the ether which transmits light and heat and perhaps gravitation, or whether it is in the form of electrons emitted from the sun, it is at any rate a no less important fact of the sun than gravitation itself. The sun is also a great magnet, and beside the powerful magnetic fields that develop in sun-spots, there is a permanent general magnetic field similar to that which surrounds the earth, so that the sun also has a north and a south magnetic pole distinct from the poles of rotation.

We see then that gravitation is not by any means the only force exerted by the sun, but that electric and magnetic forces play an important part in its influence upon the earth; if, moreover, radiant heat and light are also electromagnetic phenomena, as most scientists hold, then indeed the real meaning and potency of the sun is expressed in these two ways: the sun is a center of gravitational and of electrical force, in relation to the earth.

The sun as a great reservoir of electrical energy

And so, if our description and understanding of the sun is to be abreast of modern scientific ideas, and is to make us prepared for future discoveries, such as the astronomers' "international attack upon the sun" will surely provide, we must accustom ourselves to "think electrically" — if a famous phrase may be adapted to the present purpose. The interesting facts of sun-spots, and the great solar flames seen during total eclipses of the sun, are important in helping us to understand the electrical condition of the sun; their picturesqueness is undeniable, but what modern science cares about them for is the help they may afford in the task of unraveling the physics of the sun. For we are beginning to be able to sort things into their places, and putting those together which are really the same, and the result of the process is to teach that the sun really matters to us, and is interesting in itself, above all, because it produces electrical energy.

Light and heat products of the sun's electrical powers

It has already been noted that changes in the condition of the sun affect magnetic needles on the earth. We shall realize better the reasonableness of this when we remind ourselves that light is an electromagnetic disturbance in the ether. Radiant heat, also, is probably of the same fundamental nature; and thus the light and heat of the sun are either products of its electrical powers, or at least most intimately connected with its electromagnetic activities. This means, for the student, that in the middle of his study of astronomy he is compelled to turn aside, as it appears, to investigate the nature of light and heat, which seem to have nothing in particular to do with the study of the heavenly bodies. But the reader must not object. He is only being compelled to do what all the astronomers have been compelled to do before him. They have long studied the sun, in the ordinary astronomical ways, to ascertain its distance, size, etc., but within the last score of years they have all been compelled to turn to what is now called "solar physics" to make new instruments and build new observatories, like the great solar observatory at Mount Wilson, for the minute study of the light and heat of the sun, because to study them *here* is indeed the profoundest way of studying the sun *there!*

Electromagnetic waves pouring from the sun perceived as heat or light by us

In other words, the study of light and heat has come into astronomy, and has become as essential a part of it as has the study of gravitation itself. If all three turn out to be electrical facts of the universal ether, need we be surprised? What we now assert of the study of the sun is no less true of the study of the stars and, indeed, what is generally called the "new astronomy" depends entirely upon what we learn by studying the light and heat of the sun and the stars, in order to find out not *where* they are, which was the task, in the main, of the last generation, but *what* they are.

That vast center of radiant energy which we call the sun is continuously pouring into space, on all sides, a quantity of electromagnetic waves, as we may now name them for convenience, to which we have long given other names, according to the particular sense-organs by which we perceive them. If the retina of the eye is affected by any of these radiations we give them the name of light. If the nerves of heat in the skin are affected by any of these radiations we call them heat. If we have no senses which can be impressed by any of these radiations, we are unaware of their existence until special devices discover them — and then we hardly know what to call them.

But whether they be visible or invisible, hot or cold, bright or dark, red or violet, "infra-red" or "ultra-violet", all these forms of radiant energy are fundamentally similar if not identical, and are thought to differ only in wave length. All are simultaneously produced by the electrical state of the sun, and travel together at equal rates throughout space. Our ignorance of some, and familiarity with others, and the sharp distinctions we make between them, are due to the limitations of our senses; and until our minds can overcome this difficulty made by our bodies, and rise superior to it, no thoroughly scientific understanding of these matters can be had by us.

If all of the keys of a piano were struck simultaneously, a vast multitude of sound-waves, long and short, would be thrown through the air. That company of waves gives a very inadequate idea of the great gamut of waves, all electrical and fundamentally similar, which the sun is always sending into space. The comparison is inadequate for a very precise reason. Each key of the piano corresponds to a special string, which produces waves of a special length. The strings next above and below represent a certain gap or "musical interval" between waves of one size and waves of another. The piano cannot produce waves between those of, say, A and A sharp. But, of course, such waves exist, as we hear to our distress when a singer, trying to sing A sharp, sings something which is not A sharp nor yet A, but something between them. For the purposes of music these intervals must exist, and the piano and all other keyed musical instruments are made accordingly.

THE RELATIVE SIZES OF THE SUN AND THE PLANETS

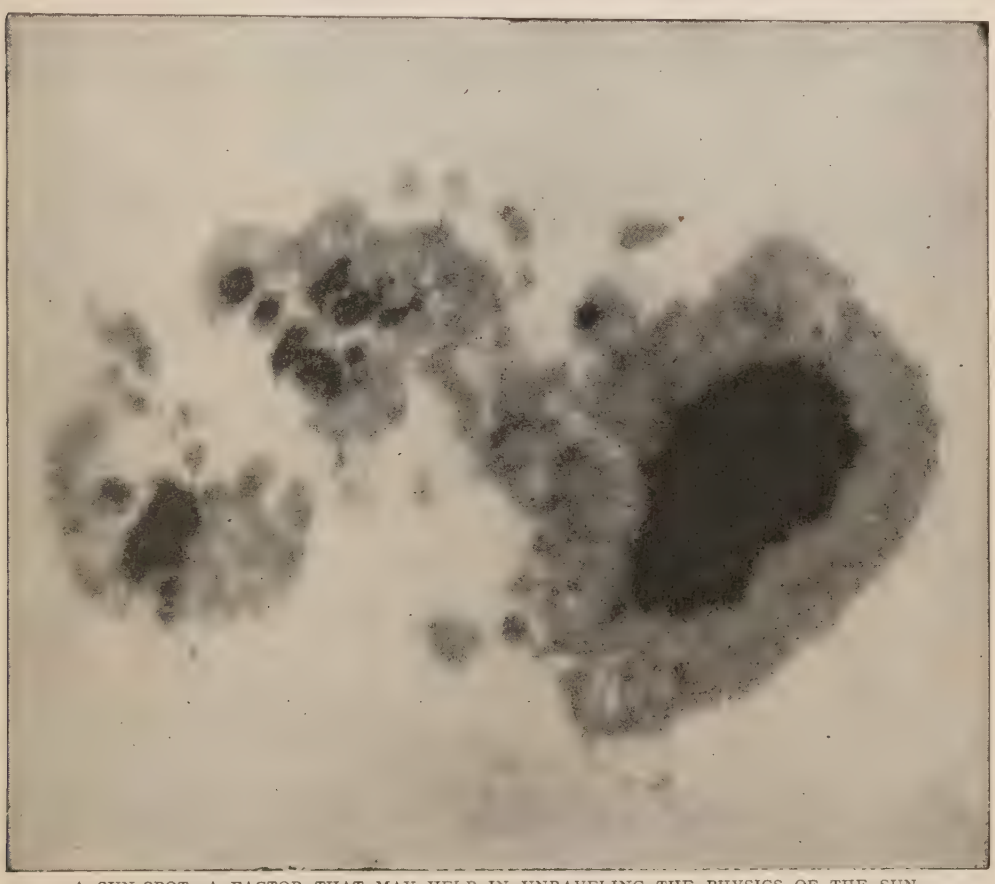
But the "full compass" of the sun's waves is full indeed, for it has *no intervals* at all. The waves it produces are of *all* intermediate lengths, by infinitesimal gradations, from the lowest note of its compass, as it were, up to the very highest; and the sun utters all these notes at once though there may be other notes outside of this range which the sun does not produce.

Astronomy and many other sciences would be in a vastly more advanced condition if the body of man were so made that it could somehow "sense" — one cannot say "see" or "feel" — the whole compass of the sun's vibrations, just as the ear can hear the whole of the compass of the piano. There are aërial vibrations below those which the ear can hear, and others above the highest we can hear. As for the compass of the sun's vibrations, we have two senses, vision and the thermal or heat sense, which we can, so to speak, join end to end, and between them they afford us direct knowledge of all of the sun's rays that men knew until a few years ago. But now we know that, even when the rays of radiant heat and the rather higher-pitched rays of light have been recognized as lying next each other in the compass of the sun, there reaches downwards a long range of radiations which are "cool" — that is, unfelt by our sense of heat; and upwards a long range of radiations which are "dark" — that is, unseen by our sense of vision.

We stand in the sun, and feel its heat and see its light. We cannot distinguish the notes, so to speak, of the sun's heat, yet the compass of solar radiations, all of which strike our nerves as heat, is really a long one,

and some of the most important advances in solar physics are being made by the study of this dark but warm part of the spectrum, and of the part, lower still, towards the bass of the sun's mighty voice, which is not less dark, but is not even warm at all. The waves down here are usually called electrical, simply because they can be detected by electrical means and none other, but according to the modern theory they are neither more nor less electrical than the higher-pitched waves, of shorter wave-length, which our senses enable us to recognize as heat, and those, higher-pitched and shorter still, which we recognize as light. Beyond the upper limit of vision we can now recognize, by the mind's eye, interpreting the records of specially made instruments, a long series of "ultra-violet rays" which are of the utmost value to the astronomer, not only because of what they promise to teach us about the nature of the sun that issues them, but also because they powerfully affect many sensitive surfaces other than that of the retina of the eye, and so afford us photographs of the sun, and of the many other heavenly bodies which also produce rays of this particular type.

Just as the nerves of heat simply give us more or less of one undifferentiated sensation, so the eye gives us more or less of the "white light" of the sun when we stand in the daylight. But this white light really covers no less important a series of gradations, in the radiations which our eyes thus interpret, than the gradations in the series of heat rays. That is why the whole landscape of science has been illuminated, ever since, by a tiny ray of light which Newton admitted to his darkened room through a hole which he had cut in the shutter.



A SUN-SPOT, A FACTOR THAT MAY HELP IN UNRAVELING THE PHYSICS OF THE SUN
Photograph taken on July 31, 1906, at the Greenwich Observatory, and reproduced by permission of the Astronomer Royal.

Exactly in front of the hole, in the path of the beam, he placed a prism, and on the opposite wall he saw a band of color, red at one end and violet at the other, which we call the "spectrum of sunlight". White light, then, is a chord of several notes — really an infinite number of notes — and the prism breaks the chord up into a band of colors, like an octave of keys upon a piano, because the rays are differently bent as they pass through the glass, according to their wave-length, and are thus thrown side by side, instead of being superposed, blended and indistinguishable, upon the screen which receives them.

THE TIDAL BORE AT MONCKTON, NEW BRUNSWICK

Extend and amplify that prism, provide specially suitable surfaces for the different parts of the spectrum to fall upon, place thermometers in the various parts of the beam, and in the dark areas, on either side, where the real beam extends, test the action of magnets upon the beam, compare the details of it with those of light from other sources, from a candle and a star and a glow-worm, and you are simply repeating and adding to the experiment of Newton, in the practical branch of science now called spectroscopy, or spectrum analysis, which may one day hang a murderer by detecting the changes produced by prussic acid in the color of blood, and the next day may tell us the chemistry of Sirius or the magnetic behavior of a sun-spot. Only a prism, through which you can see nothing clearly; yet through it man has seen further into space, deeper into the atoms of the sun or of his own blood, than all the telescopes and all the microscopes in the world had ever, and can ever, avail him.

It is this spectroscopic view of the sun which now dominates astronomers, and it is the physics and the chemistry of the sun that now engage their attention beyond everything else. These hold in them the key not only to the sun, but to the stars; not only to sun and stars, but to the history, and perhaps the destiny, of bodies no longer radiant, such as our own earth. We peer into the sun with a prism in order to see the hidden depths of the earth.

Impossibility of securing final accuracy in measuring and weighing the sun

But first, in a few paragraphs, we may rehearse the main telescopic facts of the sun, to which the work of the nineteenth century was so largely devoted. This is not to say that the work has been finally done. Every new estimate of the size, the mass, the distance of the sun will be different from the last, not merely because of individual errors of observation, which cannot be wholly obviated, but also because much depends upon the method employed, and because no degree of astronomical exactness is ever final.

These considerations deprive the "latest estimates", in astronomers' eyes, of any unique importance; astronomers know that these latest estimates will soon be superseded.

The scientific value of the various results depends not upon the results themselves, but upon the study and understanding and comparison of the particular methods employed. Let us therefore not pretend to be more accurate than we really can be, and let us aim especially at the one object that can be attained — which is to obtain sound general conceptions of the magnitudes which we are to consider.

The diagram on page 1786 shows the comparative dimensions of the sun and the planets. To state a dimension in precise figures is simply to mislead, for the sun has a great gaseous envelope, of gradually diminishing density; and who shall say at what point the sun ceases or begins?

Comparisons that give an idea of sizes in the solar system

If we note that the diameter of the sun is somewhere about 864,000 miles, the reader must particularly beware of supposing from the numbers, or from the sharp outline of the figure of the sun in the diagram, that the sun has a surface like the surface of the earth — which, in any case, is not the surface of the earth but only the level at which the solid and the gaseous parts of the earth succeed each other. To determine the real surface of the earth we should have to ascertain where the atmosphere ends, scores of miles above our heads; and the sun has no such solid surface, at any level of its substance, as the earth has.

The size or volume of the sun and its mass are, of course, two different things, which must never be confounded. So far as size, bulk or volume is concerned, we might cut up the sun into more than a million pieces, each of which would be larger than the earth. But the mass of the sun is not proportionately greater than the mass of the earth. By mass we mean, of course, the amount of matter in anything, and that is what we want to determine for the sun. We cannot speak of the sun's weight, be it noted, for weight is simply the result of gravitation; and if gravitation ceased, nothing would have any weight; but the mass, the amount of matter, in things would remain. Now, the matter composing anything may be lightly or loosely packed. Generally, the rule is that the matter of hot things is more loosely packed; heat expands them, and so we may expect the intensely hot sun to be, on the whole, much less dense than the earth.

That is indeed the case; and though the sun is more than a million times as large as the earth, it is only some three hundred thousand times as massive or "heavy". But though "heavy" conveys the idea, the word is dangerous to use, for it conveys the notion of weight, which depends on gravitation, which varies with distance, whereas the amount of matter in a thing is the same, of course, whether we study it near or from afar.

How the density of the material of which the sun is composed is estimated

What we call the "density" of any body expresses the relation between its volume and its mass — the smaller the volume into which its mass is packed, the greater is its density, and *vice versa*. In science, the density of water — under certain stated conditions of temperature and pressure — is adopted as a standard of comparison. Taking the density of water, then, as unity or one, we find that the earth as a whole (including, of course, its water) is about five and a half times as dense as water — or five and a half times as "heavy", in popular language, as a similar volume of water would be. But the density of the sun, as compared with that of water (1.00) and the earth (5.52) is only about 1.42, if, indeed, it is quite so much.

Such a figure, of course, only represents the density of the sun as a whole — its mean density. But gravitation is at work between the particles of the sun, pulling them together, and hence the weight of the outer parts of the sun, or any other such body, presses upon its inner parts, and the density of the sun, as of the earth, must increase, steadily on the whole, from its surface to its center. The outer parts of the sun, consisting of rare hot gases, are, of course, far less dense than water, but the density of the interior of the sun, where the effects of the mutual gravitation of the particles composing its gigantic mass are fully displayed, must be enormous.

The unimaginable and uncalculated temperature existing at the sun's core

Indeed, astronomers and physicists find it very hard to imagine what the state of matter can be in the center of so huge and so hot a body as the sun, where a tremendous temperature is making for expansion and a tremendous pressure is making for compression, both such a temperature and such a pressure being far beyond anything which we can experimentally produce and study on our earth.

The temperature of the sun is no less interesting than its volume and its mass, but cannot be stated with the same definiteness. We know it must be very high, and can scarcely believe — what is, nevertheless, the fact — that Newton seriously discussed the possibility that the sun may be inhabited. Recent work done by means of the spectroscope has shown that various levels in the substance of the sun vary in temperature, and it is supposed that violent local phenomena also change the temperature of the sun in various places from time to time. But the figure of 6000° centigrade, which is close to the best modern determinations, will suffice to show how hot the radiating surface of the sun must be; how much hotter the interior may be we have no means of telling.

The sun too hot to burn — as chemical combinations of combustion impossible

But even the surface temperature of the sun is, at the least, so high that, first, none of the complicated compounds necessary for the development of living matter could exist in it; and, second, not even the simpler and more stable compounds, such as water, carbonic acid or sodium chloride (common salt), could exist in it. At the temperature of the sun even such compounds would be broken up into their elements. All the elements composing these compounds exist in the sun, as we shall learn later, but they exist uncombined, and the chemistry of the sun is almost exclusively a chemistry of elements, though not exactly elementary chemistry. We said "almost exclusively", for recent spectrum analysis indicates the presence of slight amount of some refractory oxides, such as titanium oxide, in the cooler portions of sun-spots.

The amount of heat given out by the sun is a quite distinct measurement from that of the sun's temperature, and the study of it raises the further question as to its source. This is itself a matter which might be discussed in a large treatise, but we can already make one definite contribution to it from our knowledge already gained. If the sun is so hot that no compounds can exist in it, then the process of combustion, which produces heat in our furnaces on the earth, cannot occur in the sun, for combustion is the formation of compounds between oxygen and other elements, such as hydrogen and carbon. But water and carbonic acid, the respective products of such combustion, could not be formed at the temperature of the sun. We know definitely, then, even at this stage, that *the sun is not burning*. The source of the amazing output of radiant energy of the sun is not combustion, whatever else it may be.

The figures of the sun's distance from the earth constantly revised

One other figure we may conclude this chapter by stating. How distant is the sun? That question, which astronomers have so long asked, needs restatement. The earth revolves round the sun in an elliptical orbit. Therefore what we should ask is what is the mean distance of the earth from the sun, its "average distance", in popular language. This is a figure which astronomers are constantly revising, but in round numbers the mean distance of the sun from the earth is 93,100,000 miles, the diameter of the sun is approximately 864,000 miles, and its mass is close to 330,000 times that of the earth.

One other figure requires to be added. The sun rotates upon its own axis. The earth's rotation occupies twenty-four hours, which we call a day. The sun's rotation occupies twenty-five such days, but the figure varies from the sun's equator to the poles and probably from the surface to the center, for the sun is not a solid but a gaseous body. Such, then, are the chief numerical facts of the "orb of day".

THE CONTENTS OF THE AIR

The Commingled Constituents of the Gas; Its Elasticity, Weight, Humidity, and Useful Dustiness

THE PLAYGROUND OF ELECTRICITY

WE have considered the air in general in its larger relationships to the world; let us now consider, more in detail, its physical and chemical aspects.

Air, as we have said, is gas, and, being so, it behaves as such: it is elastic, as every air-gun demonstrates; it presses equally in all directions, as our own bodies witness; it expands with heat and contracts with cold, as every pneumatic tire illustrates; and its volume at a constant temperature varies inversely with the pressure to which it is subjected.

Like all gases, it is very light; at sea-level a pint of dry air at a temperature of 60° F. weighs only ten grains. Yet, light as it is in small amounts, in the huge quantities in which it occurs in nature it exercises a considerable pressure. At sea-level the atmosphere exerts a pressure to the square inch of about $14\frac{3}{4}$ pounds, or approximately the weight of two gallons of water. This seems light, considering that the column of air is about two hundred miles high, but when we take larger areas the figures are surprising. Thus, at sea-level, on a square foot the pressure is over 2000 pounds, and on an acre about 44,000 tons. The whole weight of the atmosphere is equal to a layer of mercury 30 inches high, or of water 34 feet high, spread over the whole surface (oceanic and continental) of the globe, and, according to the calculations of Sir John Herschel, amounts to $11\frac{2}{3}$ trillion tons, or $\frac{1}{1,200,000}$ of the weight of the earth. A man of ordinary build when at sea-level is exposed to a pressure of about 12 to 14 tons. Of course, if concentrated on a man's head or chest, this would be crushing, but it is exercised in all directions, up and down, from right and from left, from within and from without, and so it is hardly felt. It is this equality of pressure from within and from without that insures even the delicate film of a soap-bubble from bursting.

We have spoken of the air as having a certain weight and exercising a certain pressure *at sea-level*, but it must be clearly understood that both depend upon the enormous mass of superincumbent air. That below is pressed upon by that above, and thus becomes denser and heavier. If all the air were of the same density as that at sea-level, then a layer five miles high would suffice to account for the pressure we find there; but the air steadily diminishes in density as we ascend, and so the pressure there is due to a layer 200 miles or so high. At an elevation of 18,000 feet, the weight of a pint of air would have have shrunk to half, and the atmospheric pressure on a man on the top Mount Everest from 12 or 14 to 5 tons. On the other hand, in the valley of the Dead Sea, which is below sea-level, a man would be exposed to extra pressure.

The weight or pressure of the air is usually measured by a mercury barometer, the principle of which is as follows:

If a tube about 33 inches in length, closed at one end, be filled with mercury, and the open end inverted in a bowl of mercury, *all* the liquid in the tube will not run out into the bowl, provided the open end is kept below the surface. Some of it will remain, forming a column rising 30 inches above the surface of that in the bowl. Now, mercury is a heavy liquid, and yet

BAROMETER AT BASE OF A MOUNTAIN

whatever the size of the tube, it remains at a height of 30 inches. If a similar experiment be made with water, it will be found to stand in the tube always about 34 feet.

What holds the liquids up? Undoubtedly it is the weight of the atmosphere resting on the surface of the bowl. It forces the liquids up the tubes just as the pressure of the gas in a bottle of soda water forces it up the central tube and out at the nozzle. If this be so, then if we ascend a hill so as to reduce the weight of the superincumbent air, the mercury ought to fall in the tube; and that is just what it does. In fact, the mercury is found to rise and fall as the weight of the atmosphere increases and decreases, and, by noting the height of the mercury, we can measure the pressure of the atmosphere. That is the principle of the familiar mercury barometer, or weather-glass.

In other barometers known as aneroid or dry barometers the mobile mercury is replaced by the elastic corrugated top of an air-tight metal box, partially exhausted to avoid heat movements. This elastic top falls and rises as the pressure of the atmosphere increases and decreases. The movements of the metal top are transmitted to a lever, and through this to a pen or pencil, which makes the record on a revolving cylinder for future reference.

At sea-level the height of the mercury column is about 30 inches; at 18,000 feet (since, as we have said, the pressure at that height is only half that at sea-level) only 15 inches. At 21 miles high the barometer would stand at half an inch.

In a general way, the barometer falls half an inch for each 900 feet of ascent, and thus altitudes can be roughly measured. But it must be remembered that when air is heated it expands, and thus becomes lighter per unit volume, quite apart from the matter of altitude. It must also be noted that water-vapor in the air diminishes the density of the air. Further, the average normal barometric pressure at sea-level varies in different parts of the globe. There is a zone of maximum pressure on the sea between latitudes 30° to 35°, and the pressure then declines gradually towards the poles.

A PICTURE OF PORTSMOUTH HARBOR BY A MASTER OF ATMOSPHERIC PAINTING

This water-color painting by J. M. W. Turner shows the way in which cloud and mist affect the clearness of a landscape.

FACING PAGE 1792

We have spoken of the air as a collection of gases. What are the gases of which it consists, and where did they come from, and what do they do besides rushing about and exercising pressure?

The chief gases in the atmosphere are oxygen, nitrogen, carbon dioxide, water-vapor and argon, and there are traces besides of helium, krypton, neon, xenon, hydrogen, hydrogen sulphide, nitric acid and ammonia. The average volume composition of the gases in the atmosphere is given in the following table.

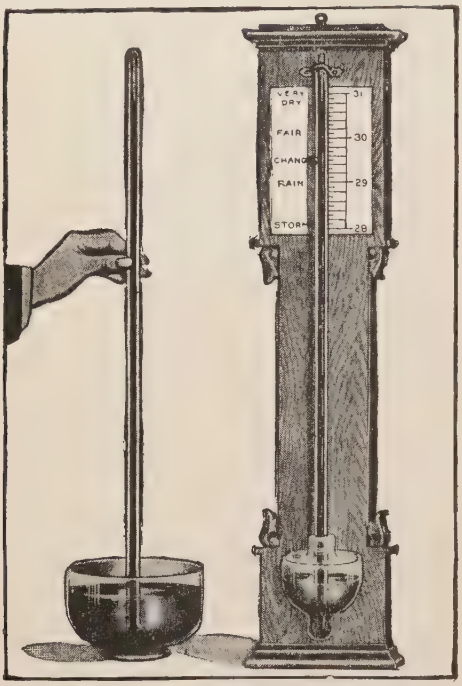
Gases	Volumes Per Cent
Oxygen	21.00
Nitrogen	78.00
Carbon dioxide	0.03
Argon	0.93
Water-vapor	Variable
Helium, krypton, neon, xenon, hydrogen, hydrogen sulphide, ammonia	Traces

The gases of the air are not chemically combined: they make up only a mechanical mixture wherein the molecules of all the gases fly about freely and independently.

Let us look for a moment at the property of some of the gases.

The wonderful gas oxygen, the king of all gases, was first discovered by Scheele, a poor Swedish drug clerk in 1773. In 1774 Priestley obtained it by heating red oxide of mercury and collecting the gas given off. As his work was carried out without knowledge of Scheele's experiments and as he first published his results he is usually called the discoverer of oxygen. He found that combustion took place better in it, and that mice lived better in it, and he came to the conclusion that it was very pure air — "between four and five times as good as common air." He inhaled it himself, and reported: "The feeling of it to my lungs was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy for some time afterwards." A few years later the French chemist Lavoisier made an analysis of the air, and showed the place of oxygen as one of its constituents. In this way modern chemistry began with the introduction

Oxygen is a colorless, odorless gas. Besides forming more than a fifth by weight of the atmosphere, it forms eight-ninths of all the water of the world, and more than half the crust of the earth. It plays the leading part in the vital function known as respiration, and on its chemical activity combustion depends. Sulphur, phosphorus, charcoal and even iron wire when well heated will burn vigorously in oxygen.



THE PRESSURE OF THE ATMOSPHERE APPLIED TO THE MERCURY BAROMETER

If a glass tube about thirty-three inches long is filled with mercury, and the lower end placed open in a bowl of mercury, that in the tube will run into the bowl until thirty inches remain in the former. Then it will stop. It is held up in the tube by the pressure of the air on the surface of the mercury in the bowl. If the air becomes lighter the mercury in the tube will sink; if it becomes heavier the mercury will be driven up higher. This is how the barometer works. The pressure of the atmosphere was discovered by the Italian Torricelli.

The proportion of oxygen in the atmosphere is wonderfully constant, and extreme limits would seem to be 21 to 20.6 per cent.

Ordinarily a molecule of oxygen consists of two atoms, but sometimes it occurs in a three-atom combination. In this triatomic form it is known as "ozone," which has a very strong odor and increased chemical activity. It is usually prepared by electrical discharges through the air, and by the oxidation of phosphorus. Owing to its great chemical activity it is a great purifier of the air, burning up all organic matter with which it comes in contact. Ozone, in nature, is formed by the action of the ultra violet rays of the sun on the oxygen of the air. As the lower dense air is not permeable to these rays, ozone is more abundant in the cold dry dust free upper air and is scarcely found at all in the dust laden city air.

Carbon dioxide was first distinguished from air by Van Helmont about 1620; in 1755 Black called it "gas sylvestre" and in 1785 showed it to be an oxide of carbon. It is colorless, odorless and half again as heavy as air. In the processes of combustion and respiration, carbon and oxygen unite and form this gas, and it is also given off in large amounts from the ground, specially in volcanic regions. At ordinary temperatures and pressures water takes into solution about its own volume of the gas; and the carbonic acid solution so formed has a somewhat corrosive action on the rocks of the crust of the earth.

It is from the carbon dioxide in the air that the green plants obtain their carbon; and since all animal life ultimately depends on vegetable food, carbon dioxide may be said to be the keystone in the arch of life; yet animals suffocate and lights refuse to burn if immersed in this gas. When carbon dioxide meets with lime it enters into combination with it, forming carbonate of calcium; and if lime-water be shaken up with air the clear liquid becomes whitish and opaque, owing to the formation of carbonate of calcium.

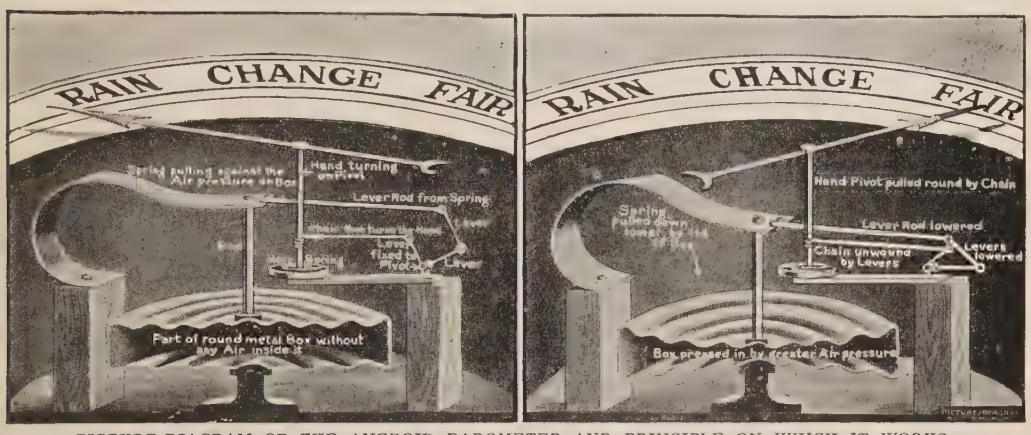
Likewise, if the breath be bubbled through lime-water, the carbon dioxide in the breath will form carbonate of calcium, and will render the clear fluid turbid. The carbon dioxide can be liberated again from the lime by treating the carbonate of calcium with an acid, such as vinegar; and if eggshell, or a piece of chalk, or a piece of marble, or carbonate of calcium in any other form, be treated with a suitable acid the carbon dioxide is liberated in a similar manner.

In open air the percentage of carbon dioxide hardly varies, but in closed rooms it often increases considerably, and the increase is usually considered a criterion of the impurity of air.

Nitrogen is a most negative gas: it has no color, no smell and no pronounced affinities. It simply dilutes the other gases of the air, and gives the atmosphere more weight, force and filtering capacity. It is, moreover, the original source of the nitrates in the soil, from which plants assimilate their nitrogen.

The gases of the atmosphere are always well mixed; and if any gas be formed in excess in any open locality it is quickly dispersed and lost in the general mass of the atmosphere. This is due to that movement of gases known as "diffusion", which causes them to intermingle automatically with each other until a perfect admixture is effected. Liquid also, even of different densities and arranged in separate layers mixed with the oxygen, nitrogen, carbon dioxide and other gases of the air. Water-vapor is lighter than oxygen and nitrogen. Thus at a temperature of 50° F. it is one-third lighter than air.

It is commonly imagined that the air sucks up the water, but that is a quite erroneous conception of evaporation. The air merely helps to warm the water, and to keep it warm, but even if there were no air above the seas and other bodies of water, still the vapor of water would rise. It is heat that agitates the molecules of liquid water, and that drives them into the air as molecules of gas that dash to and fro. The higher the temperature of the air, the greater the amount of water-vapor the atmosphere will contain.


RAIN CHANGE FAIR
Hand turning on First
Lever Rod from Spring
Part of round metal Box without any Air inside it
RAIN CHANGE FAIR
Hand Pivot pulled round by Chain
Lever Rod lowered
Chain unwound by Levers
Levers lowered
Box pressed in by greater Air pressure

PICTURE-DIAGRAM OF THE ANEROID BAROMETER AND PRINCIPLE ON WHICH IT WORKS

in one vessel in order of density, the heaviest lowest, will in time if mutually soluble form a perfectly homogeneous mixture. Solids are also diffusible, but gases possess this property in an eminent degree.

Like all gases, those of the air can be converted by cold and pressure into liquid and solid. At a temperature of 318° F. below zero air becomes a liquid, and, at a still lower temperature, a solid.

Water is a liquid, but its liquid state is unstable. It evaporates at all temperatures; very rapidly at high temperatures, and less so at low temperatures: but even when frozen solid water still evaporates and changes from ice into vapor. There is therefore always some water vapor, or water in the gaseous form,

Thus, at 32° F. the air can hold 1–160th, at 59° F. 1–80th, and at 86° F., if saturated, it holds 1–40th of its weight of water-vapor. Roughly, for every increase of 27° F. the amount of water-vapor the air can hold in proportion to its weight is doubled. *Vice versa*, every fall of 27° F. halves the air's capacity for water-vapor, and, accordingly, any drop in temperature is liable to cause a deposition of water-vapor from the air in the form of mist, cloud, rain or dew. If the air at any temperature contain its full quantum of water-vapor — if it be saturated, that is to say — then a very light fall of temperature will suffice to reduce some of the vapor to a liquid state; but if the air be not saturated a considerable fall may take place without condensation of the vapor.

The amount of water-vapor in the air may be expressed either by its weight per unit volume (absolute humidity), or by the proportion it bears to saturation (relative humidity). Thus we may say that air contains 9.4 grams of water-vapor per cubic meter; or we may say that it has a "relative humidity" of 75 per cent — *i.e.*, it contains 75 per cent of the total water-vapor it is capable of holding.

Meteorologists usually find the absolute and relative humidity of the air by a comparison of the readings of a wet and a dry bulb thermometer. If we wrap a wet cloth round our head it cools our head; and likewise if we wrap wet muslin round a thermometer bulb (thus making it a wet-bulb thermometer) it cools the thermometer, but the cooling in both cases depends on the rapidity of evaporation, and this, again, depends on the relative and absolute humidity of the air; and if we know the difference between the wet and dry bulb reading, and also the barometric pressure, it is easy, with the aid of formulas or tables, to find the absolute and relative humidity of the air.

The average relative humidity of the air in this country is about 66 per cent. As the air cools at night it becomes able to hold less and less water-vapor, and finally the layers near the ground may become saturated and any further lowering of temperature will cause a condensation of water-vapor in the form of dew. As the morning sun warms the air again, the relative humidity falls. In California the relative humidity may drop from 100 per cent at dawn to 22 per cent at noon. A hot wind may quickly lower the relative humidity 50 or 60 per cent. There may be as much as 80 per cent difference between the relative humidity of cool indoor and warm outside air under a tropical sun.

In dry, hot countries the relative humidity is very low. At Assouan on the Nile the mean relative humidity in the hours from 10 A.M. to 6 P.M. is 30.5. At Bloemfontein the annual mean relative humidity is 58.5. In the heart of the Libyan desert it may be as low as 9.

It has been customary to attach a good deal of importance to the relative humidity of the air; and meteorologists note the relative humidity as if the percentage figure had a precise and definite significance, but, as a matter of fact, relative humidity has very little meaning considered by itself. A relative humidity of 60 per cent at freezing-point has a very different meaning from a relative humidity of 60 per cent at higher temperatures, for when the air is cold and the relative humidity is 60 per cent, a slight addition of vapor will cause saturation, while when the air is hot and the relative humidity is 60 per cent, much more water-vapor can be added before the saturation point is reached.

THE EFFERVESCENT LIBERATION OF CARBON DIOXIDE

The absolute humidity of air — *i.e.*, the actual amount of water-vapor in it — is of especial importance, in that water-vapor both contains a large amount of latent heat, and also condensing to clouds reflects back the radiant heat of the earth.

The higher we ascend, the rarer and colder does the air become, and therefore the less water-vapor does it contain. Half the total water-vapor of the atmosphere is below 6500 feet, and three-quarters below 13,000 feet, while at 29,000 feet, the height of Mount Everest, there is hardly any water-vapor in the air at all. Not only is high air dry air, but, owing to its rarity, it is very *drying* air; and at high altitudes we find that dead animals dry up and mummify without decaying.

be considered dust; and dust particles of some kind or other are found everywhere in the lower atmosphere. The winds steal dust from the crust of the earth, from fields and deserts. The ocean breezes snatch salt from the ocean spray.

The volcanoes shoot dust high into the heavens. The furnace chimneys soil the sky with their carbon soot. Everywhere there is dust, dust, dust. It is surprising, too, to find how far dust can be conveyed. The sun has been darkened in Teneriffe by

THE CONDENSATION OF WATER-VAPOR IN THE AIR: MIST IN THE WOODS

When water-vapor condenses in the atmosphere, it may form either rain or clouds or mist. When it condenses on cold objects near the ground, it is called dew.

The other gases of the atmosphere — argon, helium, neon, krypton and xenon — are so inert, and occur in such small quantities, that they need only be mentioned.

Besides gases, however, the air contains dust, germs and radioactive matter.

All small particles of matter suspended in the atmosphere, whether grains of salt, or grains of sand, or organic débris, must

clouds of dust borne across the sea from the desert of the African mainland. Red dust from China has been found in California, and fragments of microscopic animals have been found in the air of Portugal which must have been carried right across the Atlantic from America. The smoke of burning Chicago reached as far as the Pacific Coast, and African microörganisms have been detected in the air of Berlin. The eruption of Mont Pelée strewed dust on Barbados, 100 miles off, to such a depth that the weight of it was several tons to the acre.

Dust is also added to the atmosphere by meteorites. Every twenty-four hours from ten to twenty million meteorites visible as shooting-stars, and many more too small to be seen, invade our atmosphere; and meteoric dust can be found both in the air and in the silt at the bottom of the sea, though its fall there may not be recent.

Insignificant as dust may seem, it is yet of great importance to the world. In ordinary quantities, as we have seen, it is the main cause of the blue color of the sky; while the coarser, thicker dusts produce variegated and splendid color effects. The gorgeous sunsets produced by volcano dust are well known, and the course of the dust round the world can be traced by the clouds of glory that accompany it on its journey. And the function of dust is more than artistic. Ordinary everyday dust it is that gives sunlight by day its soft and diffuse character, by catching and reflecting the sun's rays. Except for the dust, as we have said, we should see the sun and the stars in a black sky; the surface of the earth would shine, but it would shine as a glow-worm in the dark. Light passing through a dustless dark box is unseen, and only if dust be added to the air does the air become sunlit.

The soft, shimmering light of twilight is produced by dust in the upper layers of air reflecting the light of the sun after sunset — that is, after the sun has set below our horizon. Dust colors the sky and lights the sky, then; but, paradoxical as it may seem, dust also darkens the sky, for dust is the scaffolding of clouds and mists and fogs. Dust, the lightener, darkens; dust, the dry, makes the rain-clouds. Water-vapor is itself invisible; it is only when it condenses as minute drops of water that it forms clouds and mists and fogs; but, without something to condense upon the water-vapor cannot condense, and the dust provides cold condensing surfaces. The presence of ions or electrified particles of gas in the air would also serve to cause condensation; but the quantity of ionized air is so slight that without the dust in the air we should have practically no mist, no clouds, no fog. The air would become supersaturated; and, if there were no particles in the air for the vapor to condense upon, every object on the earth's surface would become a condenser. Every blade of grass and branch of tree would drip with moisture; our clothes would become soaking wet; our houses damp, and the walls and every object in the room wringing wet.

TWILIGHT'S GLOW, SOFT AND SHIMMERING BY REASON OF DUST IN THE UPPER AIR

Whether the water-vapor condenses as cloud, or mist, or fog, depends on the quantity of dust present — the scantier the dust, the coarser will be the condensation.

The amount of dust in the atmosphere varies with the altitude, direction of the wind, locality and many other circumstances. As a rule, the air is most laden with dust in large cities, and indoor air is dustier than outdoor air. The amount is usually stated as so many particles per cubic centimeter. On the top of the Rigi mountain, in Switzerland, 420 to 12,000 particles per cubic centimeter were found; and over the Pacific Ocean, 280 to 2125 per cubic centimeter. In London outside air the number of particles found runs as high as 80,000 to 116,000 per cubic centimeter; while in a laboratory 1,860,000 particles per cubic centimeter, or 30,318,000 in a cubic inch, were counted. Smoking-rooms contain even more, since every puff from a cigarette contains, it is calculated, about 4,000,000 particles of dust.

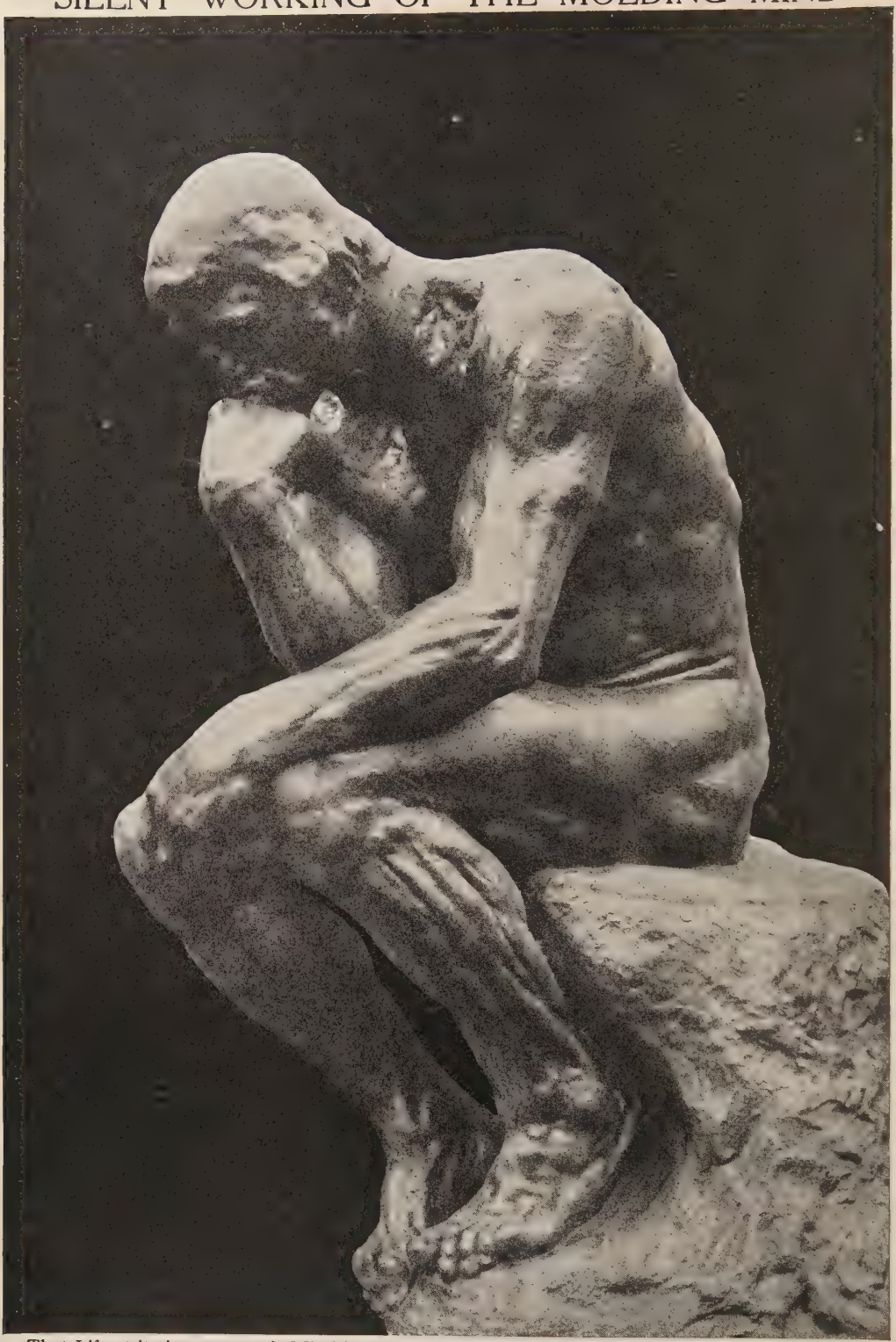
Germs must be considered along with dust, for they are just a special kind of dust. The ubiquity of germs is most surprising. Every sugary liquid left uncovered is soon invaded by yeast-cells and other fermenting organisms, and all dead organic matter is soon attacked by the microbes of putrefaction. But still germs are by no means so ubiquitous as lifeless, inorganic dust.

Tyndall exposed a thousand culture tubes to the air of London, and found that every one was invaded by germs. On the other hand, no germs invaded twenty-seven tubes open to air on the Aletsch Glacier (8000 feet). Indoors, in dark, dirty rooms, germs abound, and in a gram of dust from a room in Paris no less then 2,100,000 germs of various kinds were found.

It is a well-known fact that the atmosphere is charged with electricity, as shown by the electrical phenomena accompanying a thunderstorm. But the air is always charged with electricity, even in calm weather, and there is always a certain amount of electrical tension between earth and atmosphere. The tension is highest in winter, and lowest in summer, and is especially increased by the condensation of vapor. Generally the upper strata of the air are charged with negative electricity, just as the surface of the earth, while the intervening layer of air is charged with positive electricity. The electrical tension is so great in clouds that lightning will sometimes leap across between clouds as much as ten miles apart.

HOW SALT FROM THE SEA-SPRAY IS CAUGHT UP BY THE WIND

SILENT WORKING OF THE MOLDING MIND



That Life at its inmost core is Mind is suggested in this tense figure concentrated on one thought.
From the great sculpture "The Thinker," by Augustin Rodin,

ONENESS OF LIFE AND MIND

Mind the Underlying Motive-Force of the Living World Aiming to Transcend Itself

LOVE AND INTELLIGENCE HAND IN HAND

NO theory of evolution can be called anything but a makeshift that does not offer us a positive explanation of the greatest triumph of evolution. That is the intellectual and moral nature of man. Though natural selection, mercilessly destroying incapacity to live, has had to be reckoned with at every stage in this process, we see clearly that it has not constructed either intelligence or love, though it may have first tolerated and later confirmed them. We require something more, if we are to bring the characteristic facts of man into the evolutionary scheme at all. So beggarly has always been the merely mechanical and negative theory of natural selection to explain the evolution of man's higher nature that, from the first, Dr. Alfred Russel Wallace, the co-discoverer with Darwin of the principle of selection, has always denied that this principle would account for these greatest triumphs of evolution. He has invoked a non-scientific, supernatural explanation for the origin of the *psyche* of man; and though we cannot accept that explanation here, and do not find it necessary or desirable, we should note that one of the original discoverers of natural selection has always proclaimed its hopeless inadequacy to explain the greatest facts of evolution.

Those greatest facts are clearly two, though they are two in one, and we shall consider them separately in the light of the long foregoing discussion, which has given us the successive contributions to the theory of evolution, from Lamarck, at the beginning of the nineteenth century, to Bergson, at the beginning of the twentieth. The two supreme products of evolution for which we have to account are intelligence and love.

These products we see in their highest form in man, and our explanation must include man. But, after all, we are evolutionists; we have studied the world of life in general, and we see clear evidence of intelligence and of love among the lower animals. Man is doubtless unique and unparalleled, but his characteristics, though so great, are not *new* in the history of life, and do not require us, all of a sudden, to abandon any theory which will carry us as far as from, say, the amœba to the ape.

We have already seen that the line of intelligence is one of the three great lines along which life has evolved. It has become most evident with the evolution of the particular type of nervous system which is characteristic of vertebrates, and which has been rising in complexity and in actual bulk from the earliest fishes up to man. The older materialist theory of evolution teaches that intelligence, and even consciousness, of which intelligence is an aspect, appears with the appearance of the brain, and as a consequence of it. Random variations in the protoplasm of germ-cells, controlled by natural selection, make the brain; and when this structure has been formed, consciousness and intelligence begin to appear.

However, we know consciousness and intelligence, in a primitive form, are older than the nervous system of man, older than the nervous system of the fish, older even than any nervous system. They are part of the original nature of Life. They can be found in the lowest living organisms; and their appearance at their height in man is a progressive and purposive consequence of their inexhaustible "thrust," from the beginning of life at all.

Evidently animal psychology, popularly supposed to be the somewhat imaginative hobby of leisurely and elderly gentlemen, becomes a matter of life and death to the evolutionist who has come so far. Evidence of anything that can be called intelligence, in dog or cat or bird, is not merely a curiosity or a tale for an idle moment, but a fact for which science and philosophy are breathlessly waiting. We are not going to argue the point here. Overwhelming evidence of animal intelligence has already been presented in the section devoted to animal life, and that fact is a definite *datum* for evolution to interpret. It exalts the animal world, without in any degree debasing man, except for those strange people who cannot realize the idea of absolute worth, and only count honor or capacity worthy by contrast with lesser things.

Evidence of mind to be found in the lowest forms of life

But the proof of intelligence in ape or cat or dog does not suffice, for all of these are high in the rank of vertebrates, and possess a definite and complicated brain. The materialist theory, according to which consciousness is only a kind of phosphorescence that spreads around a brain of a certain stage of development, may still be arguable from the dog as from man. It is necessary for us to look very closely at the lowest forms of life, or, at any rate, at forms in which no nervous system whatever, let alone a brain, is to be found. Of course, intelligence and consciousness of any kind will need more looking for here, and will escape casual observation, for we cannot expect them to appear so saliently as when they have fashioned, or Life has fashioned, the special structure through which they appear so well; but the evidence is to be had, and its importance for science and philosophy can obviously not be overestimated.

We can afford to go as low even as the amœba and the humblest infusoria. Of course, they obey physico-chemical laws. So does man, and the fact is nothing to the point. But when we examine them closely, we find it impossible to explain their movements by reference to physico-chemical terms alone.

The existence of feeling and response in the humblest forms of life

The casual observer is content with such an explanation, but the various men of science who have really devoted themselves to this study, from Maupas, in 1883, to Jennings, in the last few years, have clearly proved that in these humblest manifestations of life there is evident "an effective psychological activity".

These creatures exhibit "behavior". They feel and respond — a notable fact in itself — so long as they are alive, but they do more: they learn, and choose, and refuse, and adapt themselves. We have already seen that life has taken a different course in the vegetable world, but it is to be remembered that the humblest plants exhibit these psychological traits also, and that in higher forms there is clear evidence of something psychical, even though it be imprisoned in its wall of cellulose. Lord Morley has referred to Wordsworth's famous declaration of his faith that "every flower enjoys the air it breathes" as a "charming poetic fancy and no more, and it is idle to pretend to see in it the foundation of a system of philosophy". We are not so sure today that Wordsworth did not express, doubtless with poetic license, a truth which *is* essential to our system of philosophy. But this is not the place in which to do more than simply state the existence of evidence suggestive of psychical traits appearing in the vegetable world.

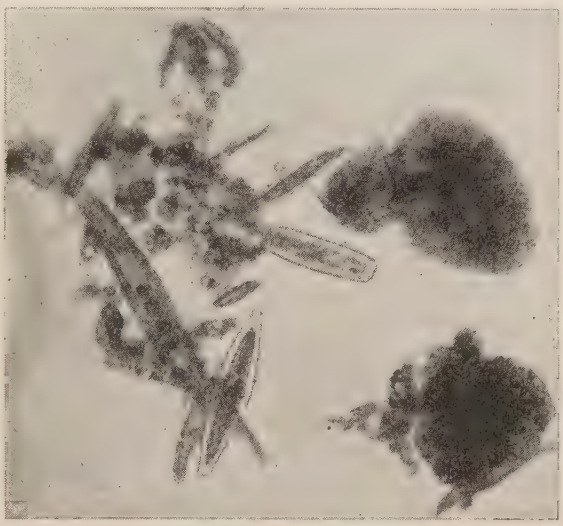
Life and mind are one through the whole scale of being

With that statement the argument is complete that mind and life are fundamentally co-extensive. Where there is life there is mind; and the phenomena of mind, at their highest and rarest, are natural and vital, and are evolutionally connected with and continuous with the facts of life in its humblest forms.

These — need it be insisted? — are tremendous statements, alike for science and philosophy, and are a subject for volumes. Our present concern with them is their bearing on our theory of evolution. The proposition that life and mind are really one:

that the function we call mind precedes and creates for itself the structure we call body, including the nervous system and the brain, even of man, is the *only proposition* on which we can base a theory of evolution that is worth a glance. The evidence for it has here been summarily stated; and the reader who would inquire into it further must consult Bergson's "Creative Evolution", and Dr. McDougall's remarkable newer volume on "Body and Mind". Here let us realize how valuable the perception of this truth is, and we cannot do so better than by looking at the alternatives.

One, already alluded to, is that, in short, of "drawing the line" at man. Thinkers of this school can accept the idea of evolution in plants without reserve, and they can accept it in animals as far as man. When they come to man they feel bound to distinguish. As regards his body, they have no doubt. His relation to the bodies of animals is duly discussed elsewhere in this work at considerable length, and is so evident that they do not gainsay it. They may not have, none of us may have, an adequate theory of the manner in which evolution occurs, but that does not matter; the theory that would take us as far as the ape will certainly take us as far as the body of man.



A PAIR OF AMŒBÆ ATTACKING DIATOMS

Amœbæ have free motion in water; the lower amœba is seen to have enveloped several diatoms in its substance. This picture is magnified 20,000 times.

But these thinkers cannot accept the view that the *psyche* of man is also an evolutionary product. When mind becomes so glorious, it seems wholly separate and original to them, and they feel compelled to say that this highest part of man is a "special creation". The difficulty of this view is extreme if we remember that the thinkers who hold to this theory recognize the relation between mind and brain, and go so far as to admit the brain to be an evolutionary product.

This, in other words, is to call the function a special creation, and the structure a product of evolution. Such a doctrine is plainly desperate, derived from the feeling that science must be abandoned, and logic, too, when we reach this point. But that would be a lamentable conclusion if it were true, and to accept it would be to abandon science and discredit it, not only here but everywhere. The truth that mind and life are one, and have thus evolved together, delivers us from this *impasse*.

No less does it deliver us from the violent contradiction of our own creed which is evolved in asserting that evolution goes on and on, unrolling new and more complicated forms of one thing, living matter, until, all of a sudden, there appears a staggering novelty, with no history, called the intelligence of man. The evolutionist cannot deny or discredit that intelligence, for that is to discredit his own theory. And if he says that it suddenly comes without a history, he is also denying his own theory that evolution is universal, and that there are no exceptions to it. Thus the evolutionist, of all men, requires to see the truth that mind and life are really one, for that doctrine alone will enable him to make and complete a statement of evolution at all. Without it he must leave out the *psyche* of man; and who would care a rap for his theory then?

All this is great gain; inestimable gain, if we recall what we were asked to believe, by representative evolutionists, in the nineteenth century. It allows us to assert, without the monstrous self-contradiction of materialistic evolution, that the *psyche* of man is an evolutionary product.

The study of life is, in the final analysis, the study of mind

It makes evolution infinitely more glorious and important than if it were merely the evolution of bodies. It raises incalculably the study of the behavior of animals and plants, of every grade and in all possible circumstances, and it exalts biology, or the study of life, as mind alone can exalt anything. In the Universe, said Sir William Hamilton, there is nothing great but man, and in man there is nothing great but mind. We feel compelled to agree, whoever we be; but now we see that the study of life, even in its rudiments, and even in its mere physical mechanism, *is* the study of mind, which becomes at last, and which illuminates beyond words, the study of the mind of man.

But this transcendent gain of ours, as compared with the generation of evolutionists before us, involves also a loss, if to lose the worthless is loss. For, once we have grasped the relation of mind to life, once we have realized what evolution therefore asserts — which is the evolution of the minds of Shakespeare and Socrates and Newton from the feeble intelligence of some far-distant ancestor — we find that we have lost our comfortable assurance that we had an efficient theory of evolution. The automatic process whereby forms which cannot survive do not survive, which we call "natural selection", and which, even ten years ago, was thought to be "an efficient cause of evolution", is seen in the full measure of its irrelevance and inadequacy. There have been many bad dramatists, before and since Shakespeare. Their dramas are dead, and his alive. This is natural selection in a typical form. And we have hitherto talked of evolution at large as if this natural rejection of bad dramas had written "Hamlet"!

How Mind is the underlying motive force of the life of the world

Certainly we have lost what was not worth losing, and now we realize that we are very much in need. We still have to explain, even only to name, the motive force of evolution, but, once our need is known, it can be met. The motive force of evolution is psychical. It is the impetus of Life-that-will-not-be-denied, which "sweeps through the dull, dense world", and which we feel and exhibit and know at first-hand in ourselves whenever we really are ourselves. This is to assert that, in our century, we are compelled to state the theory of evolution in terms of mind instead of matter, and that the very theory which was supposed to be, and was stated as if it were, materialistic becomes the best warrant for the great doctrine, held by the supreme thinkers of all ages, that Mind is the underlying and motive force of the living world.

The original psychical impetus of Life expresses itself, we have already seen, in various evolutionary forms, of which intelligence is one. Here we need say no more of it in itself, but must pass on to note its historical relation to the other great triumph of evolution, which is love, the essential constituent of the moral nature of man and, in humbler yet often noble forms, of many of the lower animals.

Why Mind has been excluded as a section from this work

But before we observe the peculiarly dependent character of intelligence, let it be noted how the foregoing argument justifies, from the standpoint of science, the omission of any section called Mind from this work. The critical reader will observe that nowhere in these pages has mind been denied or dismissed as an unreality or as outside the scope of science; nor could anyone deny that there exists already a great science of the mind, called psychology. It has been formally laid down in the section on the Universe — a term which should surely include everything — that Mind is at least one of the ultimate realities of the Universe, and yet no attempt has been made to deal with it there, and it was even pointed out that in studying, for instance, the behavior of the heavenly bodies we must deny any interference with them by Mind, and must exclude Mind from those pages. Yet we have no section on this great theme. The reason will now be apparent. Mind and life are not things apart, much less are mind and man, the highest form of life, things apart.

Only by the evolution of love is the evolution of intelligence possible

The subject of Mind needs no special section, because the sections Life and Man are bound up with it, because life is ultimately psychical, and because no discussion of man could be other than dishonoring to the subject and the writer which did not regard his mind as the essential part of him — a proposition which now sounds all the juster when we have learned that Mind is, after all, the essential and all-important part of all life.

The special problem now before us is the evolution of the intellect; and the proposition which we shall lay down is that the evolution of intelligence, culminating in its highest form, the intellect of man, necessarily and absolutely depends upon the simultaneous, or rather the prior, evolution of love. These two, then, which we have called the triumphs of evolution, and which reach their highest in the mental and moral nature of man, are to be proved interdependent, and their association not an accident, still less a misfortune, but rather a necessity.

The sum of the matter, then, is that only by the evolution of love is the evolution of intelligence possible; and this statement must be weighed against that theory of evolution, unjustifiably based upon Darwin's theory of natural selection, which asserts that evolution depends upon a brutal struggle in which charity, sympathy, mercy, forbearance, pity are weakness, and lead to degeneration. This abominable theory, for which Nietzsche is chiefly responsible and which, since the death of Sir Francis Galton, has been renewed by certain advocates of eugenics who wish to humanize man by brutalizing him, is the direct opposite of the truth, as expressed partly by natural selection and chiefly by the new theory of evolution to which the last chapter of this section referred at considerable length.

On the Darwinian theory itself, love and pity are products of natural selection, and are therefore justified, and must be assumed to have a value for and in evolution. They are as demonstrably in the ascendant, from the humblest vertebrates up to man, as the brain is, and can no more be called degenerations than the brain can. To turn round and condemn them in the name of evolution is therefore to deny evolution itself. But let us look at the facts: they will display the evolution of something which can only be called organic morality.

We are here concerned with that particular line of evolution which yields us the vertebrates, intelligence and man. The case of the line which yields us instinct, through the invertebrates called insects, is different, for the evident reason that the instinctive animal needs no help nor education, but is born perfect as far as it goes.

Organic, reproductive and moral evolution interdependent along the road of life

Let us note these facts for comparison when we come to look at intelligence. Along our line the facts, in brief, are that from the earliest fishes (to begin no lower) up to ourselves, the reproductive act increasingly displays a moral aspect. Reproduction, the production and care of other individuals, becomes the chief opportunity of altruism, which is other-ism. The reproductive function always tends to become more difficult and exacting with the increasing worth of the individual produced. The new individual is born, not more and more efficient and competent as life ascends, but *less so* — the supreme paradox of the living world. It thus needs the greater display of what we have called organic morality on the part of its parents. Thus organic evolution, reproductive evolution, and moral evolution are interdependent, along the great line which leads through the vertebrates to man — the only open road of life.

The highest vertebrates, the mammalia, of which man is the last and highest, surpass all the past. In the mammalian mother, organic morality has advanced further than in any of her predecessors, for she possesses bodily organs solely designed for the benefit of others — the unique distinction of the mammalian breast. As the mammalia ascend, the periods of gestation or expectant motherhood, and of lactation or nursing, increase, reaching their longest and most exacting in our own species.

The evidence further shows that the more the mother gives, the greater her devotion and labor and faithfulness, unconscious and conscious, "organic" and super-organic, the more helpless is her offspring, and the longer so. Contrast the young reptile, or even the chick, with the kid, and the kitten, born blind, lame, helpless. But then compare kid or kitten with a baby, say at six weeks old. The animals can now feed themselves as they run about. The child is still helpless. It needs incessant care in order to keep it alive. It is unarmed, naked, defenseless; a poor match for the kid of its own age. Yet man survives. This creature, not one specimen of which would survive its birth for twenty-four hours if left to itself, becomes the dominant species of the earth, the highest form of life that we yet know.

Natural selection selects love and morality because they serve life

Natural selection is by no means mocked. The baby has, or rather its mother has for it, some factor of "survival-value" which entitles it to survive. Its name is love. The higher the race, the more helpless are the young at birth, the longer do they need parental care, and the more assiduous must that care be. This parental care furnishes the baby, for the time, with the weapons of its success in the struggle for existence. It is uniquely deprived of other factors of survival-value, being at its birth the most helpless of all the forms which life has ever produced; but parental care constitutes for it a factor of survival which more than compensates for the absence of all the rest. We may and must freely grant that natural selection is impersonal and non-moral. It has no bias in favor of beauty of body or the "beauty of holiness". It rejects whatever cannot live — altruism in excess or bacteria that are not poisonous enough. It selects or tolerates whatever can live, without a trace of moral bias. But it is concerned to select the fittest, and thus, in man, it selects the most moral.

Morality and love, then, are not an absurd invention of the priests; sympathy is not "the morality of slaves", invented by an enslaved people under the name of Christianity, as Nietzsche declared; nor does it oppose the operation of natural selection, which Nietzsche and the neo-Nietzschean eugenists declare to be the only means of giving us the superman. The statement of natural history is that *natural selection selects morality*. Love is older than mankind, far older than any existing church or creed.

The enemies of love have appealed to natural selection; and to natural selection they shall go. Even this mechanical, negative, material, lifeless factor of the evolution of life returns a verdict in favor of morality, as the emergence and triumph of love prove. But we have already learned that natural selection creates nothing, whatever it may select, or rather whatever it may tolerate. We still require, therefore, a positive explanation of the emergence of love. It can, of course, only be the explanation of Shelley and Spencer and Bergson — the explanation here given. The evolution of love and of intelligence is explained because love and intelligence serve life, or because they are native in the primal essence of life.

Life a progress — each generation leaning over the next in love

The aim of life is to live and to transcend itself. Hence, as we have learned, its invention of death in the service of higher and fuller life to come. Life is a progress and a movement. In its course it makes individuals, whom we think of as *things*, though each of them is really part of a progress. "At times, however," says Bergson, "in a fleeting vision, the invisible breath that bears them is materialized before our eyes. We have this sudden illumination before certain forms of maternal love, so striking and in most animals so touching, observable even in the solicitude of the plant for its seed. This love, in which some have seen the mystery of life, may possibly deliver us life's secret. It shows us each generation leaning over the generation that shall follow. It allows us a glimpse of the fact that the living being is, above all, a thoroughfare, and that the essence of life is in the movement by which life is transmitted."

Finally, we have to justify the assertion that intellect and love, which seem so different, are interdependent, and in so doing to explain the paradox that the most competent race is born the most helpless. This has been worked out years ago by Dr. McDougall, particularly in his book "Body and Mind: A Defense of Animism", published in 1911, and in masterly fashion by Bergson. In general, while instinct cannot learn, it need not, for it is born perfect within its limits, which it will never transcend. *Intelligence has everything to learn, but it can learn everything.*

Because intelligence can learn everything it has everything to learn

An intelligent being bears within himself the means to transcend his own nature, as man is always proving. To intelligence, and to intelligence alone of the three directions in which life has evolved, the road is open to the infinite. Instinct is lost in novel circumstances, and can answer no questions. Intelligence can adapt itself to new circumstances, answer novel questions, and, in its greatest moments, can create new circumstances and ask supreme questions, even though it cannot answer them all as yet.

But just because it can learn everything, it has everything to learn. Hence the key to the paradox, that the more intelligent a race the more helpless is it in infancy. To be born competent is to be born incompetent for progress. The infant is helpless because of the nature of the endowment with which it will some day help itself to the earth and the fullness thereof. And because it must be helpless, it must have the care of parenthood or foster-parenthood.

Our long argument thus culminates in certain great propositions which may here be reasserted for convenience of the reader in a short and concise form. Not only is the Nietzschean doctrine that morality is a product of man in slavery untrue, but the truth is that man is the highest product of morality. The law of nature is: *No love, no intellect; no morals, no man.* The triumphs of man are the triumphs of woman. Baby-saving is intellect-making.

This particular fact of helplessness in the human infant is due to his unique departure from the instinctive endowment of life, skilled but rigid; and the unique prolongation of his dependence is due to the unique extent to which intelligence develops in him. Indeed, to the end he is dependent upon the generations before him. Their skill and sacrifice and care have endowed him with the conditions which make his life as an intelligent being possible; his ancestors watch over the bed of the man in his glorious prime, and guide and guard his day. This is the forward purpose of life, still justifying itself. Sacrifice, devotion, love, alike for those we have in our arms, and for the future which we shall never see: these are the very conditions of the life of an intelligent species, reminding us of the fine sentence which contains the essential conclusion of Herbert Spencer's philosophy: "A transfigured sentiment of parenthood, which regards with solicitude not child and grandchild only, but the generations to come hereafter, fathers of the future, creating and providing for their remote children."

It would seem, then, that the gospel of force is based upon shameful ignorance of the facts of biology. These facts teach us that altruism has been an indispensable factor not merely in the ennobling of human life but in its actual production. They further teach us that morality is no artificial product, but an inalienable possession of humanity, older than all the churches, much older than human thought. Thus, though "Nature, red in tooth and claw", may appear indifferent to good and evil, her sun shining alike on the just and the unjust, yet every new baby teaches us that love is a cosmic product of which humanity itself is not the author but the fruit; and that, therefore, Emerson was justified when he said that "the universe is moral".

The untutored daily observation of all men in all times, and the theory of evolution, which is the highest product of the tutored observation of all times, alike teach us that altruism is an inherent factor in human life, older than all religious and ethical systems, and destined to outlive not, indeed, Truth, which "fails not, but her outward forms that bear the longest date".

PROGRESSIVE STAGES OF PLANT GROWTH

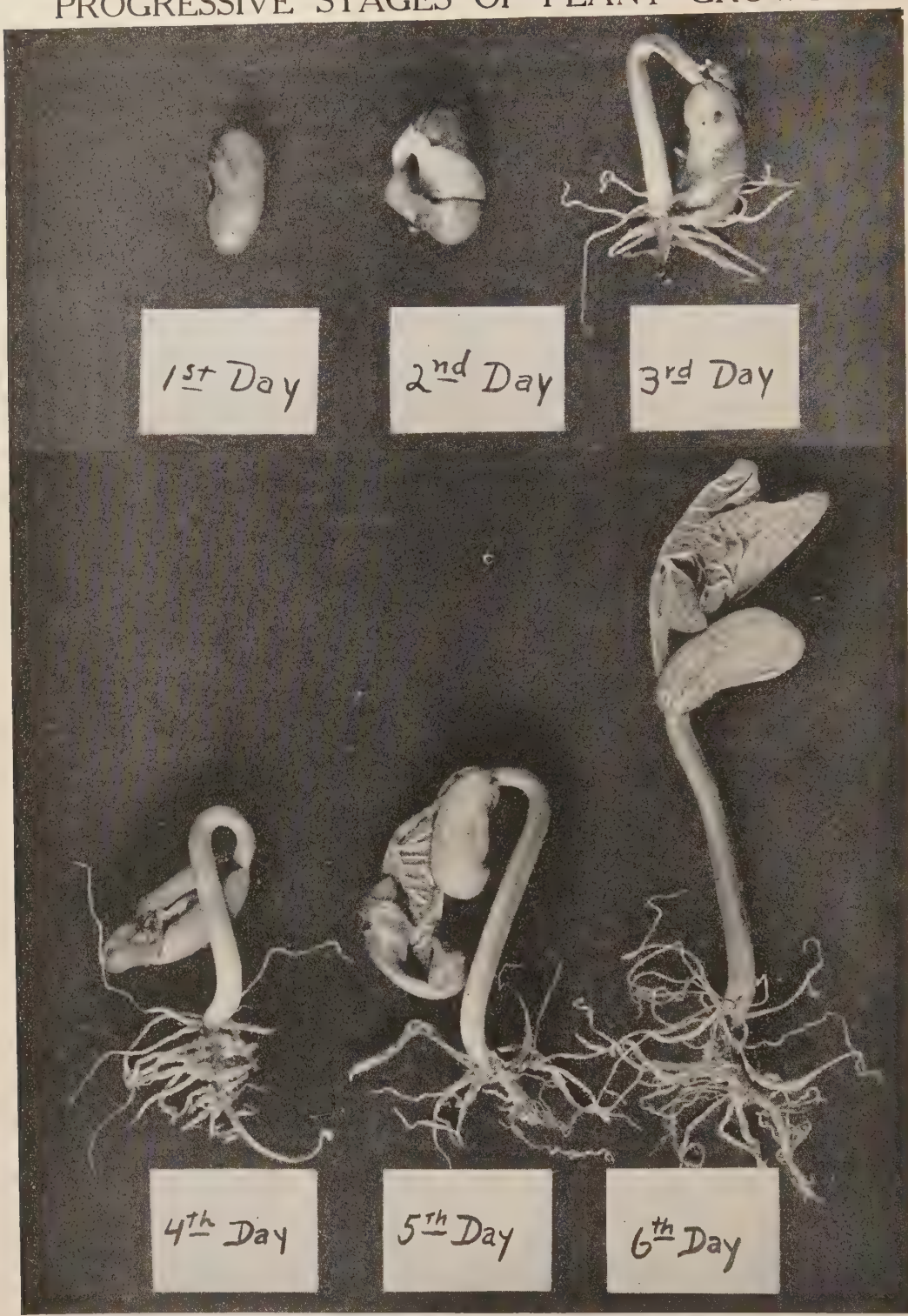


Photo N. Y. State College of Agriculture, Dept. of Plant Breeding

This photograph shows the progressive stages at germination of a bean seedling: (1) the seed as placed in moist soil; (2) seed coat breaking away and stalk emerging; (3) stalk elongated and secondary roots appearing; (4–6) plumule emerging between cotyledons and assuming erect position. Note adherence to roots of soil particles firmly held by microscopic root hairs.

A PLANT'S FIRST GROWTH

Conditions of the Germination of Seeds, and Their Purposeful Stroke Downward and Upward

EASY EXPERIMENTS WITH THE BEAN

WE have now to take up some of the further problems of growth and the function of reproduction; and at this stage we shall confine ourselves to the study of these processes as they are connected with seeds. At a later stage, when we study the organs of reproduction in flowers, for example, we shall have to consider some further points.

The most common way to raise a crop of almost any plant is by the sowing of the seeds produced by a former generation of the same species. True, as we have seen, there are other ways of producing new plants, but the sowing of seeds is the process that rises in the mind as the initial stage of the production of a new crop. It is therefore essential that we should understand something of the nature of a seed, and of its marvelous capabilities. To the ordinary mind these are wrapped in considerable mystery, all the more obscure, perhaps, from the fact that the many different processes in connection with seeds are hidden from our observation, inasmuch as they occur under the ground. Some of them, too, are of such an extremely delicate nature, and on such a small scale, that it is necessary to call in the aid of the microscope, or at least a magnifying-glass, in order to observe them.

Still, there are some seeds sufficiently large and sufficiently common to enable them to demonstrate all the important processes quite easily. Anyone who chooses can study for himself the structure of a seed, and with his own eyes watch its development from the very earliest stages, until the plant itself is formed.

No better example for this purpose could be selected than that of the common bean, for it may be taken as a type to indicate the general structure of a seed. The wheat-seed also may very well be examined; and the illustrations in this chapter indicate clearly the different stages of development, and the structures concerned, which we are now about to describe.

If the pod of a leguminous plant, such as the bean, be opened when the seed is nearly ripe, it is found that each of the seeds is attached within by means of a short stalk.

This stalk, or "funicle" as it is called, is really the means of communication between the maternal structures and those of the seed itself, and it is through it that the nourishment from the parent is transmitted for the development of the young seed. By and by the stalk dries up, and so ultimately allows the seeds to detach themselves from the parental connection. In order to ascertain exactly what such a seed is made of, it should not be allowed to become shriveled up, but rather should it be soaked in water for a few hours, by which means its separate parts can be more readily distinguished.

The outer covering of such a seed is smooth, of a yellowish color, and is characterized by a black mark at one end, which is known as the eye or "hilum". This represents the point at which the seed was attached to the funicle within the pod during its process of ripening. Close beside one end of the eye of the bean there can be seen, with the aid of a magnifying-glass, a very small aperture.

Its presence can be demonstrated in a soaked bean by gently squeezing the whole seed, when a little water will bubble out at this spot. Obviously the aperture, therefore, forms a means of communication with the interior, and apparently the only communication. There is nothing else on the outside which is noticeable.

The outer coat can be very easily removed by cutting round the edge of the seed and stripping it off. When this has been done we see that we have removed a sort of membrane, tough, and not quite transparent. This is the "testa". Within it the true seed lies, seen to be oval and somewhat flattened, and separable into two distinct halves, or "cotyledons", united by a little projecting portion known as the "radicle", one end of which is inserted in a hole in the testa, which corresponds in position to the aperture already mentioned. The other end lies between the two cotyledons, as is distinctly seen if one of these halves be removed, when the bent radicle remains attached in position to the other. The seed, therefore, in this undeveloped stage is seen to consist of testa, radicle and two cotyledons.

This is a simple enough structure, but it is, nevertheless, sufficient to contain within it all the possibilities for the growth of a complete bean plant; and the function of the various parts only becomes obvious when this seed, or bean, is either placed in the ground and allowed to grow, or else put under such other conditions of temperature and moisture as will stimulate it to growth similar to that which would take place if it were in the ground.

How the seed begins to send out the root and stem

Let us suppose that the seed is placed in such conditions, and that we can watch what happens. The first thing to which our attention would be drawn is that one end of the bent radicle grows longer, and very soon forces a passage through the seed-coat. The spot where it emerges through the coat is very close to the minute aperture, or "micropyle", already mentioned, but not actually through it. Further elongation of this radicle soon causes the seed to assume the shape seen in figure 4 of the illustration on the page facing. A glance at this illustration suggests that the elongated radicle is becoming a root, and, indeed, that is the case, for this is the root of the new plant.

Part of it, however, remains between the two cotyledons; and this part, which is curved, also forces a passage out of the opening in the coat of the seed and grows upwards. Just as the lower portion suggested the growth of the root, so does this second outgrowth, as it straightens itself upwards, suggest a stem, and, indeed, this is a new stem from which the leaves are about to be developed. At this stage the appearance is that shown in figure 5, and we have what we may term an "embryo plant". The root and the stem together thus form an axis, passing through, as it were, the two cotyledons; and these two structures, root and stem, are known as the "primary axis" of the plant.

If we wish to know where the root begins and the stem ends, it is necessary to make a much closer examination of the structure within the axis itself. It is noticed that the upper part of the stem as it forces its way out from between the cotyledons is bent upon itself, and it remains in this curved attitude for some time. This forms a kind of protection for the developing tender leaves; and although this is not obvious in a seed that is being grown simply in water, it will be quite clear if a seed in the ground be examined.

A simple method by which germination can be watched

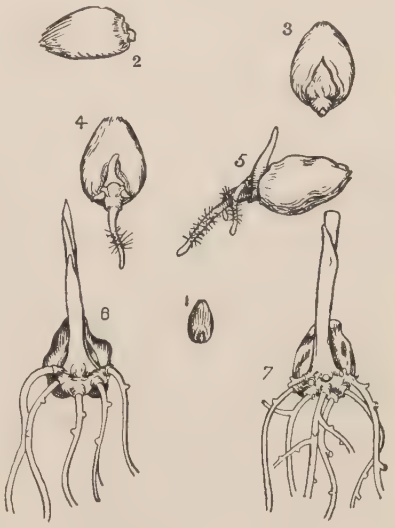
Any who wish to observe for themselves the processes we have just described may readily do so by simply taking a few beans, soaking them in water for twelve hours, wrapping them up in some thick, damp flannel, and placing them between two plates, so that one plate covers up the beans in the flannel, and keeps in the heat — just as one would place a piece of toast to keep it warm. The beans can then be examined at intervals, and the flannel kept damp, when the appearance of the radicle and the curved plumule may be easily seen.

As long as the seed is in the pod, it derives its nourishment from the parent plant from which it grows, but when it gets to the ripe stage it passes into a curious condition of inactivity. This stage may last for a very long time, during which no signs of life in the seed will be apparent at all. How long a seed may remain in this dormant, inactive condition is a much-disputed matter, and depends a good deal upon the kind of seed concerned, as well as on the environment in which it happens to be. It is a very curious stage, and is not entirely understood, but this much is certain: the embryo within a dormant seed will not live long unless the seed was thoroughly ripened first. A good deal, too, depends upon how the seed is kept afterwards. Most of the seeds used in gardens, or for agricultural crops, fail to germinate if kept for more than ten years or so, and a good many will not survive nearly so long a time. In fact, two or three years is the limit for some. On the other hand, seeds have been said to have retained their power of germinating for much longer periods.

This capacity for germinating, which constitutes, of course, the whole value of a seed, depends upon at least the following factors: the embryo in the seed must be alive; it must have supplied to it a certain amount of water; it must not be subjected to too great extremes of temperature; it is imperative that it shall have a supply of air or oxygen.

Curiously enough, it is quite impossible to tell by simply examining the outside appearance of a seed whether it is alive or dead. That is to say, external symptoms do not afford obvious evidence of the life of the embryo. The seed may be discolored, apparently dried up, wrinkled and otherwise disfigured to such an extent that it would appear hopeless to expect anything from it, and yet if it be placed under suitable conditions germination will follow. On the other hand, externally the seed may represent every appearance of being in a good condition, and yet when planted may fail to germinate, because the embryo within is dead. It is true, at the same time, that there are some seeds whose power of germination can be roughly, or partly, estimated by their color, and particularly by their brightness, but no great reliance is placed upon such unreliable methods; and all seeds that are to be used should have their germinating power tested by putting samples of them under suitable conditions.

The most usual cause of failure for germination is that the embryo within the seed has perished. We are apt to forget that this is a living structure, capable of retaining its life for a wonderful length of time, but not capable of so maintaining it indefinitely. Thus, in the case of the wheat-seed, seeds which have been kept for more than ten years are found to be quite dead, and even in three-year-old samples there will be far fewer seeds germinating than in a sample of wheat sown in the season following the crop. So the germinating capacity of the seed obviously deteriorates with its age. This is, of course, a very practical question, because it becomes of importance for the gardener and the farmer to have some kind of idea of the length of time he may keep seeds stored without impairing his chances of securing a reasonable crop.

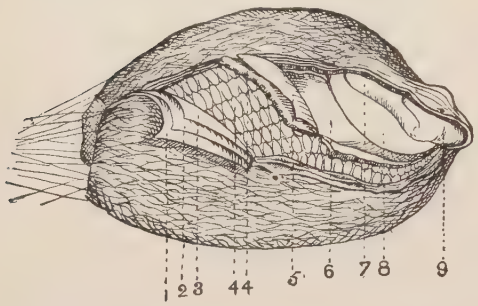


GERMINATION OF A SEED

1, Grain of wheat, natural size; 2, enlarged, showing protrusion of embryo on right; 3, the tip of the radicle beginning to appear; 4, a later stage, showing plumule growing and root hairs on radicle; 5, 6, 7, progressive stages, showing growth of plumule and roots and shrinking of the seed.

The following table is given by Professor John Percival to indicate the time beyond which it is inadvisable to use the seeds mentioned.

Wheat 2 years
Oats 2 years
Barley 1 to 2 years
Rye 1 to 2 years
Corn 1 to 2 years
Peas 4 to 5 years
Beans 4 to 5 years
Buckwheat 2 years
Turnip 3 to 4 years
Swede 3 to 4 years
Mustard 3 to 4 years
Mangold 3 years
Carrot 3 years
Cabbage 3 to 4 years
Kale 3 to 4 years
Kohlrabi 3 to 4 years
Clovers 2 to 3 years
Sainfoin 1 or 2 years
Lucerne 3 or 4 years
Most grasses 2 or 3 years



THE PARTS OF A GRAIN OF WHEAT

1, Epicarp; 2, mesocarp; 3, endocarp; 4, testa; 5, seed-coat; 6, endosperm; 7, plumule; 8, cotyledon or scutellum; 9, radicle; 7, 8 and 9 comprise the embryo.

The next condition necessary for germination is that there should be a sufficient quantity of moisture in the form of water. This can be seen at once experimentally by keeping seeds dry at different temperatures where they have an exposure to air, when it will be found that no growth occurs. On the other hand, if they be allowed access to moisture, not merely in the ground but even in a dish, the moisture is enabled to penetrate the seed-coat, and so reach the interior, passing especially through the minute aperture of the micropyle. This moisture very soon reaches the radicle, which, as we have seen, is the first part of the embryo to make its appearance. The immediate result is that the bean, or other seed, swells and softens, these two changes preceding the appearance of the growing radicle.

Other conditions necessary for germination of the seed

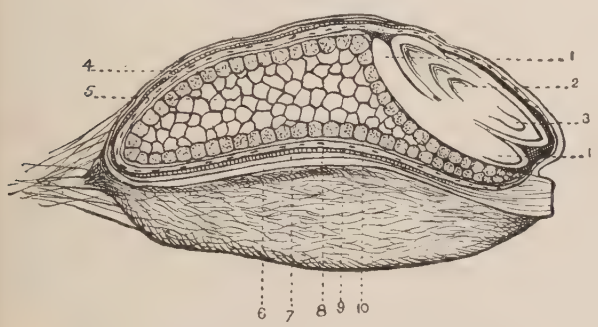
But not only is it necessary that the embryo should be alive and healthy, and that moisture have access to it in order that germination may take place — a certain amount of heat is also required. Gardeners and farmers observe this when they sow beans or other seeds in the ground during the winter months, when, instead of the radicle making its appearance in a few days as it does in spring and summer, the seed remains dormant until the temperature rises. There is great variation, however, in the actual temperature required to start the germination process. Some embryos make their earliest growth when the weather is only just above freezing-point, other species requiring much warmer surroundings. In every case there is a temperature at which that particular kind of seed germinates most readily. In the case of the bean it is about 28° C.

A still further necessary condition of germination is a supply of air or oxygen, although it is not quite so easy to demonstrate the necessity for this. Still, it can be done by placing the seed in an atmosphere of hydrogen, or some other gas which displaces the oxygen of the air. Then it is found that, even though both moisture and adequate heat be supplied, still germination does not now take place.

These three necessary factors of moisture, oxygen and warmth immediately suggest to us that we are dealing with an actual process of life itself; and when we make a further experiment and notice that the growth of the seed does actually absorb oxygen from the air, and give off carbon dioxide into the air, we are still more convinced of the fact, because this is precisely what happens in the respiration of ordinary living creatures. Another proof can be offered in a simple experiment. If a few beans be placed in a bottle containing ordinary air, and the neck of the bottle be corked up, a chemical test at the end of twenty-four hours will show that the air has been replaced by carbon dioxide gas, the oxygen obviously, therefore, having been utilized by the seeds.

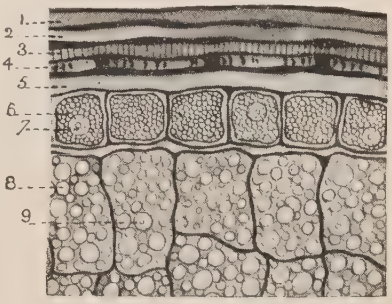
The actual part played by water in the process of germination has been already partly discussed in earlier chapters, but the additional point may be mentioned here that it is clearly of the greatest assistance in so softening the tough seed-coat as to enable the embryo to start growth and penetrate its covering.

The earlier stages of growth, such as those illustrated in our pictures, depend entirely upon the two cotyledons for their supply of nourishment. These cotyledons, at first thick and bulky, will be observed, as growth goes on, to become reduced in size, getting considerably thinner. As a matter of fact, their interior is a store house filled with food for the maintenance of the growing embryo; and this suggests to us another important function on the



LONGITUDINAL SECTION OF A GRAIN OF WHEAT

1, Cotyledon or scutellum; 2, plumule; 3, radicle; 4, cells containing aleurone grains; 5, cells containing starch grains; 6, epicarp; 7, mesocarp; 8, endocarp; 9, testa; 10, seed-coat; 4 and 5 comprise the endosperm.



CROSS SECTION OF A GRAIN OF WHEAT HIGHLY MAGNIFIED

1, Epicarp; 2, mesocarp; 3, endocarp; 4, testa; 5, seed-coat; 6, aleurone grains in cells; 7, cell nucleus; 8, starch grains in cells; 9, cell nucleus.

growing plant. Such movements are quite clearly indicative that we are dealing with a living young thing and one of a specific type. Thus, when the bean planted in the soil has reached a stage at which the radicle appears, this structure is observed to turn at once downwards into the soil, and continue to grow in that direction. This happens no matter in what attitude the bean was originally placed.

The stem, or plumule, exhibits movements equally definite, but exactly opposite in direction. From the very moment when it emerges from the seed-coat between the cotyledons, its tip, which is at the end of its curved portion (see figures 4–7, page 1811), begins to grow upwards in the opposite direction from the root; and, again, part of the moisture absorbed by the cotyledons — namely, that it dissolves the nutrient matters and enables them to be carried to the embryonic areas themselves, and especially to the radicle and the young stem, as they respectively appear. The earliest stages of germination cannot occur in such a seed as the bean without the presence of the cotyledons, as can be easily proved by cutting off the radicle and the stem of the embryo immediately they have made their appearance and pushed themselves through the seed-coat. It will then be found that development ceases, the supply of nourishment having been cut off.

One of the most interesting points in connection with the process we are discussing is that of the movements that take place in the different parts of the young if the seed be uprooted and the position reversed, the experiment fails, the stem once more asserting its inherent living tendency to seek the surface of the soil. A very interesting experiment, that illustrates these marvelous movements extremely well, is to sow a number of beans in a shallow box, placing the seeds in a variety of different positions. If they be examined at the end of a week or so, the above facts will be made obvious.

We have taken the case of the bean as an example of the process to be noted in germination because the seed itself is a common one, and sufficiently large for its structures to be easily examined. It must not be thought, however, that the process differs in any essential particular in the bean from that which takes place in other seeds.

While it is, of course, perfectly true that seeds differ immensely in their appearance, size, color, weight, texture and so forth, they nevertheless all have this at least in common: that every one contains within it a young embryo stored and protected between the seed-coats. These latter may be large or small, but the proportions only differ, not the structures.

There are few exceptions to this rule. The exact manner in which the embryo is disposed within the seed is not, however, the same in all kinds. Its size, its manner of appearance, and its rate of germination vary very considerably in different species.

In the case of the seeds of the white mustard plant, the two cotyledons do not remain inside the seed-coat and below the soil as they do in the bean, but escape together from the seed-coat and actually come up above the soil surface, where they soon assume the appearance of ordinary green leaves. In fact, they are the first leaves of the mustard plant. A little later the stem appears between the two, and as it grows upwards develops from itself the secondary or rough leaves of the mustard plant.

It may be well to mention in passing, since the term is in very common use, that all plants the embryos of which are characterized by possessing two cotyledons receive the name of "dicotyledons". This group is a very well-known and numerous portion of our flowering flora.

Some seeds, however, do not depend entirely upon the cotyledons for their storage of food, even though they belong to the group of dicotyledons. For example, the seeds of the ash and the potato, both of this class, have a store of food quite distinct from the cotyledons. When such a separate store of food exists it is known as "endospermous", and the seeds possessing this store are termed "endospermous", or "albuminous", in distinction to those of the bean and mustard type, which, having no separate storage of the kind, are termed "exendospermous", or "exalbuminous".

Finally, a grain of wheat is not exactly a seed but a mass of nourishment that contains a seed. When germination occurs, the seed within the grain gradually comes to occupy the whole of the interior. The embryo takes up only a small part of the space, mainly utilized by a store of floury nourishment. When the embryo begins to grow it is seen to consist of a shield, or "scutellum", attached to this is the plumule, this exhibiting a short stem with leaves of a sheath-like nature. Three rootlets usually appear. As the embryo grows, the endosperm diminishes, so it is obvious that this endosperm is the store of food upon which the young plant is dependent during its early growth. The shield has the function of transferring the food to the different parts of the growing plant.

MARVELS OF ANIMAL ENGINEERING

CENTRAL PORTION OF A GREAT BEAVER DAM NEAR LAKE SUPERIOR

ANIMAL HOME BUILDERS

The Intelligence That, through the Beavers, Finds Expression in Elaborate Engineering Works

THE MASTER CRAFTSMAN OF THE WILDS

MAN was not the first home-maker. He was not the first engineer. He was not the first to make provision against the morrow. He was anticipated in each sphere by the brute creation. Insects and birds, and certain of the mammals, set an example that he was slow to copy. Perhaps the imitation was unconscious; perhaps it was partly conscious.

We have learned from the wild animals how to hunt them, and what it is safe to eat, and it is not unlikely, therefore, that primitive man may have got some of his first ideas in engineering from the quadrupeds about him. Indisputably, the cave dweller must have envied the beaver its lodge and the burrowing creatures their subterranean cities. With his mind, with his hands, with opposable thumbs, with his erect carriage, he has outstripped all the rest of creation. The results that he has attained are, of course, incomparable, but the achievements of the beaver are almost as incomparably ahead of those of all other animals — "animals" in the common acceptation of the term.

The life of the beaver is really more highly organized than that of the mightiest gorilla or of the astutest monkey. The rough shelter of interlaced branches of the tree upon which it squats is the only attempt at a dwelling made by any of the exalted order of Primates. Yet the brain of the ape or monkey is the finest brain in the world next to that of man. It is surprising that with the imitative faculty so highly developed, the Primates have never essayed home-making. One difficulty, of course, is that Primates and beavers occupy different regions.

But it is only the lower animals that build homes and store up food. Their habitations are regarded as evidence of degeneration in some animals — as evidence that failing by other means to keep pace with the tide of evolutionary progress, they have had to crawl below ground. This argument does not apply to the animals with which this chapter deals, a group belonging to the rodent family, a numerous and specialized assemblage of mammals, the majority of which will be separately considered. The list is headed by the beaver, our finest natural engineer. He was the first to throw a bridge across a stream, and he remains the only animal capable of the feat. He was the first mammal to build a home above ground, and today man is his only rival.

It is impossible to guess how the habit originated. The food of beavers consists in the main of the bark and twigs of trees, notably the willow and poplar; but in summer, when they leave the river and wander inland, they flourish upon corn and grain. It is suggested by a thoughtful naturalist that at some time early in their history a beaver may have gnawed through the trunk of a tree overhanging a rivulet, till it fell across the stream and formed a natural barrier, that held up the water to a permanent depth. To suppose that this hypothetical pioneer immediately grasped the significance of accident, and finished the dam, and that his progeny at once learned the lesson and adopted the plan, is to credit the beaver brain with an intelligence and reasoning power altogether too high. But the process must have come about gradually by some such means.

Had there been a beaver that could suddenly dam rivers, build lodges and make roads and canals for the conveyance of his materials; and had such an animal transmitted his gifts to his offspring, he would have become the ancestor of a type of animal which, supposing its gifts to be progressive, would have challenged man for the supremacy of the world. For, eliminating all the fiction about the beaver's making windows to his lodges, and similar legends, his work remains the marvel of the animal world.

What does it mean? It means that he must estimate in advance the course of events in a stream, must realize that the abundant water of today may vanish, either from lack of rain, or through the supply being cut off by frost. He must reason out how best to combat this danger, and must find that the only way is to dam the stream, and so maintain a constant depth. Having secured his waterway, he must then provide a home that will be safe from attack by his enemy, the glutton, and at all times give him access to a sufficient depth of water free from frost, in order that he may reach his food stored beneath the stream.

And this is only half his work; his timber-felling far from the stream, his conveyance of the logs to the water, and the canals that he makes for the purpose, all require the planning of a marvelous mind. Strike out every suggestion of fancy and embroidery, and the feats of the beaver are still the most challenging fact in animal psychology. Says Auguste Forel: "It seems to require much less nervous substance for fixed or instinctive reasoning than for reasoning actual, individual, new, and combinative." And he describes instinct as reasoning organized, systematized and automatized. Let us see whether the beaver's work suggests reasoning or only obedience to blind impulse.

Beaver works are carried on for hundreds of years; but this can only be in a low-lying, swampy region, where the beavers may run canals far into the woods, and so not consume the trees faster than new trees can grow. We have now, however, to imagine a couple of beavers beginning work *de novo*. We have to remember that in some parts of North America and in Europe, where these animals have long been persecuted almost to the point of extermination, they may occasionally lapse into mere burrow-makers in the banks of streams. The beavers we have in mind, however, are those that remain among the vanishing glories of the northern United States and Canada. The earliest duty of our pioneers is to excavate a burrow in the bank, or throw together a roughly built lodge to serve as a temporary home while defense and permanent mansion are prepared.

BEAVERS AT WORK CONSTRUCTING A DAM FROM LOGS AND FRAGMENTS OF WOOD

The photographs on these pages are by A. A. Allen, Lewis Medland, W. P. Dando and C. Reid.

The first problem to be determined arises from the stream. If it is a small and sluggish stream, a light dam of woodwork will suffice. If it is a swift-flowing rivulet, the case demands a more ambitious effort, and the dam must be made like a wall. The shape, too, has to be determined. A straight dam serves to check a gentle current of water, but to withstand a rapid flow a curved dam, with the convex face opposed to the current, must be built. Here, then, are problems calling for "reasoning actual, new, and individual". A decision having been reached as to what form the dam shall take, the beavers set to work to cut down trees. Those nearest the water and inclining towards the stream are chosen, and gnawed through near the root. As a rule, but not always, the tree falls towards the water. The boughs are then bitten off and peeled. The bark and thin twigs serve for food; the thick boughs themselves are gnawed through into suitable lengths for the dam. The trunk of the tree is similarly served. The logs are rolled into the water by the builders, who use their forepaws for the purpose, and push with their bodies, raising themselves upon their hind legs and using the heavy tail as a lever. It is to be noticed that the thicker the branch or trunk, the shorter are the sections into which it is cut, obviously in reference to the strength of the beaver.

THE SUPREME NATURAL ENGINEER — THE BEAVER

The foundation of the dam may be either of mud and stones or of brushwood, or both. In either case the logs have to be securely anchored to guard against their being floated away by the stream. This is effected by their being thrust into the mud, or into brushwood already so attached. In the case of a lighter dam, building with logs and twigs now proceeds apace. Sticks and poles and twigs are interwoven and plastered with mud, so as to form a substantial but not invincible barrier. In the case of the "solid-bank" dam, as it is called, less wood is employed, mud and stones taking its place. The stones weigh from one to six pounds, and are carried held against the beaver's chest by the forepaws. Mud is transported in the same way, and beaten hard with the paws. The heavy trowel-like tail is not used for the work, but is simply the rudder, though the report with which it strikes the water as the animal plunges in may be employed as an alarm signal.

THREE TREES IN COURSE OF DESTRUCTION BY BEAVERS, WHOSE DAM IS TO BE SEEN IN THE BACKGROUND

It probably took man a long time to make a sluice for his lock-gates. The beaver has his sluice, too. In the case of the woodwork dam interstices between the logs and twigs afford an outlet for surplus water by percolation, but it is different in the wall dam. Here the beaver deliberately leaves an opening at the summit, a well-defined channel through which the dammed-up water can rush when it reaches a dangerous height. Moreover, the size of this sluice is regulated by the beavers in accordance with the condition of their pond, being widened in presence of a freshet, and narrowed when the water is low. Attention is given constantly, so long as the beavers are in residence, to the stick dam, to guard against too rapid percolation and to the making good of waste at the base as the result of natural decay of materials. It is not uncommon to find one dam supplemented by a second, either close at hand or at some little distance down the same stream. This may be made in order that the one may serve as a sort of bulwark to the other, or it may be that the first has failed to dam up the water to a sufficient depth, owing to the configuration of the land, a defect which the second remedies. There are more plans in the work of a beaver than are dreamed of in the philosophy of most of us.

Our beaver friends are now ready to start in building their permanent home

The dam built, ample water is secured in which the beavers may safely swim without observation in summer and winter, more especially in the latter season, for they may roam away overland in summer and come back in autumn to repair their work and make ready for the snows. The lodge has next to be made. Here, again, discrimination must be exercised. If there be an island in the water, the probability is that the builders will choose that. They may build on the dam itself, or they may choose the bank of the stream for the site. Lodges vary considerably in size and design; they are not uniform and unvarying, like the cell of the bee, but are adapted to the natural conditions and to the changing levels of the water. Where considerable rises of water occur, the home is generally upon the bank. Some of the lodges are built wholly clear of the water, with burrows running down from the interior of the lodge to the bed of the stream; others are made with one outer wall actually in the water. The structure is of wood and twigs, the logs varying in length from a foot to a yard, and the whole is heavily plastered with mud, which, freezing in the winter, makes the lodge a stout fortress, which even the powerful claws of the dreaded glutton attack in vain.

The arch no mystery to the beaver

The beaver long ago mastered the mystery of the arched roof. His home consists of a spacious chamber, according to the age of the structure, and it is constantly undergoing repair and renewal. The chamber is oval, with a stout arched roof, and it may be eight or more feet in diameter in the case of an old lodge, while the height and breadth of the whole varies with age.

Some lodges are occupied for many years. The interior is lined with mud and twigs and vegetable fibers, as are the tunnels, which communicate with the water. These latter are masterpieces of animal ingenuity. One is known as the "wood entrance", and is a straight, bold tunnel running sheer down into the water. It is through this that the beaver passes, laden with good cheer, returning with viands from his larder, which he establishes at the foot of the dam. The food consists of bark and tender branches of trees, and as these occupy some space, he must have a straight run up into the house for them, hence the bold tunnel left for their admittance. The second, and it may be the third, tunnels twist and wind before entering the water, and constitute the highways to the pond for all but foraging expeditions. It is perhaps not too speculative to imagine that the wood tunnel may be guarded in some way when not in use, or the devious highways to the water would be useless; an enemy would enter by the former without difficulty. All the tunnels are beautifully rounded, their roofs and sides and floors strengthened with twigs and fibers beaten into the soil.

So much for the dam and the lodge. The beaver is now free to enter the water at will. In winter he has a store of food hidden ready for his wants, and it matters not how severe the frost, there is clear water for him at the bottom to which his tunnels lead him. He runs from his lodge by way of one of these tunnels, enters the water — valves enable him to close ears and nostrils — he wanders under the water until he has got such food as he requires, returns by the wood tunnel, and shares his meal with his mate and offspring in as neat and effective a home as ever was built save by the hands of man.

Time brings changes even for beavers, and the day arrives when there is no more timber to be felled within easy reach of the river. He has cut down all the adjacent trees, gnawed them into logs, and rolled them to the water. The time has now arrived when he can no longer bring down his timber in this way; the ground is broken and uneven, the task of transport beyond his strength. It is a new problem, and the solution seems really more wonderful than the work on dam or lodge. The beaver calmly sets to work and makes a canal. Surely this is beyond the province of mere instinct.

Simply with his paws the beaver excavates a channel, and clears it of obstructions in the way of roots and weeds. Then he cuts a connection with the river, and floods his waterway. That gives him a passage, it may be of some hundreds of feet. Into this he rolls the logs which he has cut, and sends them down to the river or pond with all the assurance of the accomplished lumberman. But the ground makes a sudden rise, and it is necessary to carry his canal higher. He cannot, because he is unable to defeat the laws of nature and make water flow upward. This is another new situation, perhaps the most complex that he has yet had to face. He tackles it manfully. He builds a dam across the end of his canal, a catchwater dam, which collects all the water descending over a wider area from above, and cuts a canal in which the water so caught can run. He has made a canal lock! His waterway has risen a foot, and he now has another stretch of highway along which to float his logs down to the canal dam, over which he pulls them into the long stretch of water flowing into the main stream. It is no less a miracle of achievement for an animal than is the great Nile barrage for man. Man, with all his tools and appliances, excels the beaver's dams and canals more in degree than kind, and the beaver has only teeth and paws. Can it be wondered that the beaver is a sore puzzle to students of animal psychology, that they are driven to ask if something higher than instinct is not engaged in these marvels of engineering, of foresight, of planning, of battling with new and ever-changing conditions? Captive beavers do not encourage the belief in the possibility of higher mental faculties of the genus.

TWO CANALS DUG BY BEAVERS TO CONNECT TWO SMALL LAKES

The beavers at a zoo make their canals as to the manner born. They plaster their roof with mud, they complete with logs and twigs the house which a keeper has started for them. The plastering and canal-making suggest the following of instinct; the captives have not realized that they are in a new environment and need neither. But civilized man, placed in an entirely new environment, might unconsciously do some such grotesque thing in his day-dreams himself.

We cannot carry the inquiry further. All we can do is to hope that Canada, the Northern States and Norway and the few other remaining countries to which these extraordinary animals remain, will preserve them and never mind the howls of soulless lumbermen who complain that the beavers tap their water or dam their logging streams. In a few places, like the Adirondacks and Catskills, where the beavers have been reintroduced, they have increased to such an extent that it has been necessary to trap them and reduce their numbers to save valuable timber. Still, unique, and a complete puzzle in respect of its mental attributes, this king of the rodents ought to be treasured like the okapi and the last of the bison.

Photo A. A. Allen

A FAMILIAR HOME BUILDER
A muskrat house in a marsh.

Another and more familiar home builder is the muskrat, which is found about streams and marshes throughout eastern North America. It ordinarily lives in burrows in the banks of streams, but in marshes and along lake shores it often builds quite elaborate houses of cat-tails and other aquatic vegetation that rival those of the beaver himself.

After the beaver, the rest of the engineers among mammals appear inconsiderable, though, judged by the proper standard, they are wonderful little animals. Take, for example, the chipmunks, ground squirrels of Siberia, eastern Europe and North America. They are comfortable-living little creatures, of the sort that children like to read of by the fireside on a

THE SUSLIK

winter's evening. They make quite admirable underground dwellings approached by devious galleries, supplemented by twisting tunnels to provide a ready escape in time of invasion by carnivorous foes. But it is the little amimal's care for the winter season, when its home is frozen over, that charms the child. The chipmunk is as provident as a bee, as an investigation of one store revealed. In it, snugly hidden underground, were found two quarts of buckwheat, a quantity of grass seed, nearly a peck of acorns, some Indian corn, and a quart of nuts. All this store for three or four little animals no larger than rats!

The Asiatic susliks, again, are expert miners, constructing deep burrows communicating with airy, roomy chambers. Regular storehouses are established below to contain the winter's supplies. When autumn wanes the susliks retire to their fastness and make all secure and cozy by blocking up the only entrance. Thus they pass the winter, with ample food to sustain life throughout the dreary months. When spring draws near they excavate an ascending tunnel running in the contrary direction to that by which they entered, and leave by the back door, as it were, the front door remaining sealed.

They have a system of sentries and lookouts, but not in such perfection as the prairie marmots, erroneously called "prairie dogs", in reference to the puppy-like yapping with which the older ones, posted upon a hillock to survey the surrounding country, give warning of an enemy's approach. Theirs is an admirably organized community, dwelling together in great numbers in underground homes that are called "dog towns", or villages. But with all their care they cannot keep out intruders. They habitually suffer from the rattlesnake, and dread the burrowing owl. The reptile is an invader, not a guest, and dines upon the family of his hosts. It is surprising that animals which combine so

A GROUP OF GERMAN HAMSTERS

well to build and guard their homes should not have wit enough for combination against this scaly foe.

These marmots, unlike the gophers, are purely herbivorous; the gophers supplement a diet mainly vegetarian with mice and young birds, and are known to have feasted upon the bodies of slaughtered bison with which the prairies were once dotted. With its more varied diet, the gopher should in time outdistance the marmot. All the marmots resemble each other pretty much in habit and in the wonderful homes that they construct below ground. Many lay up a store of provisions against the winter, but this is not the case with the Old World marmots, or with the New World woodchucks, which sleep so soundly through the time of frost and snow that they need no food.

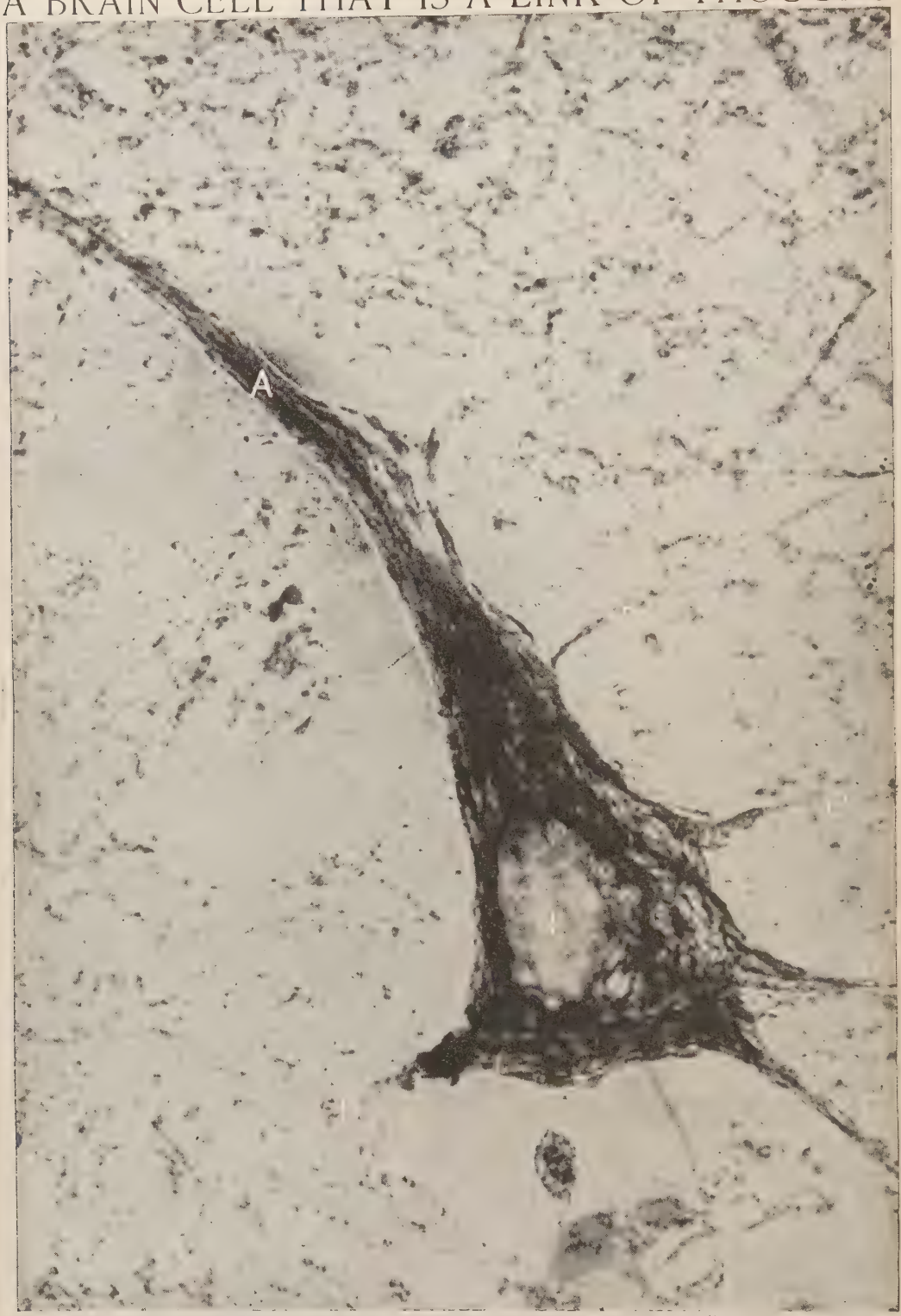
Two remarkable miners are the hamster and the viscacha. The former has the more ambitious dwelling, with many corridors, a complete suite of rooms for the family, several granaries, one for each kind of corn, and one for fruits and roots. This is quite a model home, and so well do the animals thrive that at times they become a serious menace to harvests in Europe and Asia.

The South American viscacha is master of a remarkable home too, an underground labyrinth of tunnels and chambers. But whereas the hamster is as clean and fastidious as a badger, the viscacha has the

THE SOUTH AMERICAN VISCACHA

instinct of a rag-and-bone gatherer. He stores at the huge entrance to his colony all the refuse of his food, and roams far to collect things to add to his collection. When a friend of Darwin lost a watch on the Argentine pampas, he looked no farther than the home of the viscachas, and there he found it, displayed to advantage amid bones, stones and thistle-stalks. Having become home-owners, the viscachas gratify a passion for property by their rubbish heaps, and in this resemble the bowerbirds. The members of the viscacha family are better known as chinchillas from their beautiful soft fur. So valuable has this fur become that certain species are threatened with extinction unless suitable protection be given to them.

A BRAIN CELL THAT IS A LINK OF THOUGHT



A MAGNIFIED PHOTOGRAPH OF A SECTION OF BRAIN SHOWING PART OF AN "ASSOCIATION" CELL, STAINED TO REVEAL THE REACHING OUT OF THE AXONE AND DENDRITES

A, axone, part of which has been cut off; *D*, dendrites; *N*, nucleus of cell.

MAN'S ESSENTIAL LIFE

The Dependent Yet Dominant Nervous System, For the Sake of Which the Other Systems Exist

THE SUPREME FUNCTION OF MIND

"WHAT'S past is prologue," as Shakespeare says. We have described bones and muscles and glands, the heart and the blood, the lungs and the digestion, but none of these is an end in itself nor all of them put together. In detail, they differ in man and the lower animals, but in no essentials. They clearly do not live for themselves, but for each other and for the nervous system, in which alone we find the characteristic organ of man. They support the nervous system, and it rules them; but though the first statement needs no particular qualification, the second does.

Beyond doubt these various systems support or serve the nervous system. Its powers of self-support are practically *nil*. It is shut away from the external world, and entirely depends for nourishment, ventilation and cleansing upon what the blood and lymph bring to it and take away from it. While other organs and tissues spend much labor in producing compounds that feed, or stimulate, or soothe the nervous system, it performs no such functions itself, we believe; and though it certainly produces many and various chemicals, these are highly objectionable to itself, requiring the most rapid and complete removal, and are of no use to the rest of the body, which, indeed, has to burn them up or throw them out entirely.

This dependence of the nervous system has reached an extreme point. Other parts of the body have some power of what is called regeneration. Skin-cells and gland-cells, and many others, can divide and multiply, increasing their numbers or compensating for loss. No nerve-cell can divide. The nerve-cells that are not too greatly poisoned can recover; we are learning that even nerve-cells that have been chronically poisoned with alcohol for years, and were thought to be dead, may recover if the poison is discontinued. But if a nerve-cell dies, none other can divide so as to replace it. The infant at birth possesses all the nerve-cells it will ever possess. True, as we shall learn, not all may develop, but there will be no cell-division in any nerve-cell in any circumstances. The nerve-cell is so highly specialized that it has lost this characteristic and necessary power of all typical cells. The consequence is that the nervous system is gravely limited in its power of compensating for damage, and therefore requires more care and protection than ever from those systems of the body which we have already described.

In return for their service it rules them, but the rule is much less absolute than we have until lately supposed. Thus the white cells of the blood are not under the control of the nervous system at all, nor are the ciliated cells that line the respiratory tract and are found in many other parts of the body. Again, though digestion is largely under the control of the nervous system, we find that the secretion of the digestive glands is by no means wholly under nervous control. The body is united in a double fashion — first, by the nervous system; and, second, chemically. The chemistry of digestion is largely a series of reactions, of which each stage chemically conditions the next. Thus the bowel produces a hormone called "secretin", which is absorbed and stimulates the pancreas to activity.

This is, then, chemical stimulation, chemical coördination of the body, quite distinct from nervous stimulation and coördination. We owe our gaining of this great new conception chiefly to the work of Professors Starling and Bayliss. We are learning that, both in health and in disease, the body is constantly producing and distributing substances now called "hormones", from the Greek verb *hormao* — I stir up, excite, summon, rouse to action. That is what these hormones do; and by them the various parts of the body are constantly sending messages and giving orders to each other, and thus achieving a unity and a common action, which is just what the nervous system also does in its way, and is no less indispensable.

The nervous system the system for which the whole body exists

From the point of view of the philosophy, the true science, of the human organism all this is very important, for it helps us to understand the real physiological relation between the nervous system and the rest of the body. The nervous system does undoubtedly rule, control, direct, coördinate, the rest of the body; and unless it does so things go utterly wrong throughout the entire mechanism.

But this does not mean that the nervous system exists only for that purpose, as has been supposed. On the contrary, the nervous system only does what is necessary *in its own interests;* and a vast deal of bodily management and regulation, we now learn, is done independently of the nervous system altogether, but nevertheless for the nervous system.

It is not the servant, not even the authoritative government, appointed by the people to serve them; it is the absolute object, end and aim of the whole body, which exists for it and for it alone. In the rest of the body, birth and death are continually occurring — skin-cells, blood-cells and so forth are born and die in perhaps millions daily. They and their fate are nothing. They are like the helots of ancient Athens, numerous, necessary, but allowed to exist only for the sake of the privileged few, in whom life reached its highest development. Just so nerve-cells are not born in the course of the history of the individual; or rather, they are born, once for all, long before his birth, and they last unchanged throughout his life, while birth and death go on incessantly and in their service.

The brain the relatively modern structure which reveals the soul of man

Ultimately, and in its essential nature, we begin to see, life is psychical. In another section of this work, where it was sought to reduce all existence to the fewest possible categories, life found no place. Ether and energy were regarded as ultimates, and a similar place was claimed for mind. Where, we may ask, does life come in? There is such a thing, and it is not named there. The question matters supremely when it is asked of the life of man. The answer is that life is ultimately not ether, not energy, though it is lived in ether, employs energy, and transgresses none of their laws. Ultimately it is psychical. Even in the lowest possible organisms recent work has demonstrated traces of choice and educability — traces of what can only be called mind; and in man supremely does life reveal its essential nature.

The overwhelming significance of this, for religion and for man's outlook upon the universe, must be evident, and we shall often return to it. If life be essentially psychical, if evidence of mind, however humble, be found wherever we look properly for it in the world of life, then the nervous system, and preëminently the brain, of man are simply those relatively modern structures in and through which the life of man, life as manifested in man, specially concentrates and reveals itself. The opposition between this view and that which regards man's mind as a consequence of his brain — a structure evolved by the ordered accidents of "natural selection" — is infinite, everlasting and all-important. The twentieth century may yet be recorded as that in which the mind of man walked out of the darkness of nineteenth century materialism into the wide light of knowledge, which asserts more surely and durably what the glaring superstitions of the past served rather to distort than to reveal.

The "psyche" diffused through all the lower organisms is concentrated in man

The first and the last function of life is mind; that was "in the beginning", and that comes first. The evolution of the nervous system in the animal world, culminating in that of man, simply means the superior concentration, effectiveness and intensity, even to self-awareness, of the dim psychical activity which is doubtless diffused through the general substance of lower organisms, and which unquestionably remains diffused through the various cells of our own bodies, as we soon learn when we study the behavior of white blood-cells, bone-making cells, ciliated cells and many more. As Bergson says: "The lower we descend in the animal series, the more the nervous centers are simplified, and the more, too, they separate from each other, till finally the nervous elements disappear, merged in the mass of a less differentiated organism. But it is the same with all the other apparatus, with all other anatomical elements; and it would be as absurd to refuse consciousness to an animal because it has no brain as to declare it incapable of nourishing itself because it has no stomach."

Mind finds expression chiefly through the brain, but also through the whole body

We affirm, then, that the nervous system contains and displays the essential life of man, or of any animal that possesses a nervous system, in the highest possible degree. But we do not assert that the essentially psychical character of life has been wholly withdrawn from the rest of the body. Very far from that, indeed, is the trend of modern psychology. On the contrary, when we study the nervous system on the assumption that the mind is a product of the brain, we soon learn that there are facts of mind the brain does not seem to account for.

We find that the spinal cord plays a part in mind. We discover the "sympathetic nervous system", and agree that this plays a part in mind. We discover that there are facts of mind, not clear and defined, like a logician's syllogism, but nevertheless part of the mind, which can only be referred to the organs of the body.

In ancient days, men thought of the liver as the seat of passion, the bowels as the seat of compassion and so forth. We do not think so now, but we do recognize that these and the other organs of the body play a real part in our psychical life. Mind is most displayed through the brain and the nervous system, but not through them only. In the concluding chapter of his "Autobiography", Herbert Spencer devoted much space to argument for the proposition that "the mind is as deep as the viscera" — that is, the internal organs of the body. No modern psychologist denies it. Mind is at the bottom of all our life. It was not invented by the brain, but it has evolved the brain as its most sufficient instrument.

The various forms of power over the body exercised by the nervous system

Thus, modern science seems to be steadily returning to the view of Plato, that the body and its organs are the musical instrument, the "organ", of the soul, which plays upon them, and reveals itself through them according to the degree of their perfection.

All this is anticipation. One other general consideration is necessary, and it is that the nervous system makes itself necessary to the rest of the body in a very remarkable way, not very long discovered, and not yet understood. Without any special study, we all know that there are nerves which order muscles, and nerves which record sensations; and we should say that these two express the whole relation of the nervous system to the rest of the body. But we find that, when the nerves running to any part of the body are divided, strange things happen. Of course, a muscle which has lost its nerve-supply is paralyzed; but let us take some other structure — say, the transparent front-window, or cornea, of the eye. This is not a muscle, and has no motor-nerves running to it. Sensory nerves run from it, and tell us when it is touched or scratched. But we find that, inside the bundle of fibers that we call a nerve, running from the cornea, there must be some which do not convey any information from the cornea, but do carry something to it.

In other words, we find that if the nerves of the cornea be divided, no matter how carefully it be protected so that nothing can touch it, soon it will undergo serious changes and will ultimately die. What has happened to it?

Why it pays all parts of the body to feed the nervous system

The answer is that the nervous system exercises, upon every part of the body, an influence regulating nutrition, which is called its *trophic* influence (compare "atrophy", and "hypertrophy"). Trophic nerves run to every organ and tissue, and keep them well. What really happens science has so far failed to find out. It might be merely that the blood-supply to the part is regulated by the nerves, which we know to be the case. But we may choose a tissue like the cornea, which has no blood-vessels in it, or we may check our observation in other ways, and we can prove that the trophic influence of the nervous system is something special, which does not depend upon, say, the exercise a muscle gets, nor upon the due regulation of the supply of blood to any tissue. It is something apart, but its importance is beyond question, for there can be no health in any part of the body which is not receiving a proper supply of this trophic influence from the system. It follows that, if the nervous system be not properly looked after by the other tissues and organs, they very soon suffer in health. It pays them, so to speak, to look after their master properly.

What, then, is this nervous system, in which the life and mind of the body are so amazingly expressed, and raised to their highest in the self-consciousness of man? It is, of course, a collection of cells. They are not wholly collected in one place, but the quotation from Bergson has already told us that the closer grouping of the characteristic cells of this system, which we call nerve-cells, is a feature of the higher forms of animal life. The earliest nerve-cells are widely distributed throughout the animal body. To deny consciousness to such an animal is simply silly, it palpably wakes and sleeps, as we do; and if it is not conscious when it is awake, what is it when it is asleep?

The widespread nerves become linked up and grouped

But in time in the lower animals nerve-cells find that they can be vastly more effective when they are grouped together, just as a collection of strings and keys, forming a piano, is more effective than a scarcely connected number of such strings all over the house. Thus we get what are called nervous ganglia. A ganglion is simply a collection of nerve-cells. Where we find, say, four or five ganglia grouped together, probably at the front end of an animal, nearest its eyes and nose and mouth, as in the earthworm for illustration, we cannot easily deny to this collection the title of a brain.

This collecting and linking up of nerve-ganglia has proceeded much further in man than in any other creature, and has reached such an extent that we find very nearly all the nerve-cells in his body concentrated in a continuous structure or organ which we call the central nervous system. Thus, if one were to deprive a man of all four limbs, by amputation at the hip-joints and shoulder-joints, he would not be the poorer by even one nerve-cell.

There are no nerve-cells proper in the limbs, none in the skin, none inside any of the muscles of the body, with the great exception of the heart. There are, however, nerve-fibers which are prolongations of the nerve-cells located elsewhere. Yet the entire nervous system has developed from the skin layer of the embryo — that is, the layer next the outer world, which it is the business of the nervous system to deal with.

The withdrawal of the chief nerve-cells into a strong bone box

But, though it is now in better and really closer touch with the outside world, and has more power over it, it has withdrawn itself to an extraordinary degree, being not merely within the body and away from the skin, but being actually incased in a great box of bone through a few holes in which it transacts all its business. Thus only the brain sees, but lives in absolute darkness. The central nervous system can be, and will be, defined, and its outgrowths can be traced to the uttermost parts of the body.

Obscure puzzle of sympathetic nervous system and its sense of well-being

We also find in the body what we can scarcely refrain from calling another nervous system, and this is known by the name, given to it by the older anatomists, of the "sympathetic nervous system". Now this system is known as the "autonomic nervous system" to indicate that it possesses a certain independence of the "central nervous system". The nerve-cells of this system are much more scattered. They are not found at all inside the skull and backbone. But they form ganglia in various parts of the trunk of the body, and the most intimate connections exist between the central nervous system and the autonomic nervous system in spite of the above mentioned "certain independence" of the last system.

The largest ganglion belonging to the sympathetic nervous system is known as the "solar plexus", or "abdominal brain". This is by far the largest collection of nerve-cells in the body outside the skull and backbone. It lies behind the stomach, and is highly susceptible to blows. When we are hit in the "wind", or "knocked out", what has happened is that the solar plexus has been shocked by a blow; and we all can assent to the anatomical assertion that this plexus is linked up with other parts of the nervous system — not least with those which control our breathing or "wind".

But, really, the sympathetic or autonomic nervous system is still a great puzzle to anatomists, and so we had better only briefly discuss it here. The prevailing notion among anatomists is that the sympathetic nervous system is the oldest part of the nervous system of man, the part which has, so to speak, been left behind in the body-cavity when the rest of the nervous system has withdrawn itself into the skull and back-bone. But there are many difficulties in the way of this view, and perhaps the only thing certain is that we cannot afford to despise the sympathetic nervous system, for we do not yet know all of its functions. We know beyond doubt that it discharges most important functions, carrying many of the nerves that control the blood-vessels, for instance.

It also probably plays a very considerable part in the trophic function of the nervous system. But especially are we to realize that the sympathetic nervous system plays a much more important part in our *minds*, in our feelings of happiness or depression, "fitness" or slackness, good or bad temper, than we suppose when we think of the mind as if it were a secretion from the brain.

No one who has ever been "knocked out" should make such a mistake; if the solar plexus can give us such unpleasant feelings when it is out of order, may it not play a large part in other kinds of feelings when it is in order? Those who know how important for the life of man is his "organic sense of well-being" will begin to see the point. If a further hint be needed, let us consider what kind of sleep we "enjoy" when a heavy supper remains undigested, and is vainly churned in the stomach.

Nerve-cells of central nervous system remarkably unlike other body cells

And now for the central nervous system itself. It is essentially a collection of nerve-cells. With them there is found some connective tissue, blood-vessels and lymphatics, but the nerve-cells are the essence of the system. A nerve-cell, however, is in many ways exceedingly unlike all the other cells we know, and requires very special description. It has a variety of projections or processes, called "dendrites", running from it, or rather to it; and the modern theory of the central nervous system regards it as a combination of vast numbers of these units — each unit, a nerve-cell, with its various projections, or processes, being called a "neuron". This neuronic theory of the nervous system has held itself against all comers, and is now fairly established.

The center of each neuron is the nerve-cell itself, or the body of the cell, as we sometimes call it. The cell may take many forms, often being remarkably large and striking in shape, like the large pyramidal cells found at a certain level of a certain part of the human brain, and shown in the photographs in Chapter 1 of this group. A nerve-cell always has a large and vitally important nucleus, and this nucleus shows different appearances at different times.

An examination of the cells through which shines the light of the mind

But we never see its chromatin breaking up into chromosomes, nor any other sign of nuclear division. This nucleus cannot divide, but has devoted all its possibilities to its own individual development. The nuclei of the cells in the highest parts of the human brain are the most exalted forms of material structure in the world, for through them shines preëminently the light of mind. The idea of nerve-cells as electric lamps, arranged in a system, already presents itself, and will be found invaluable in helping us understand many facts of consciousness.

But, after all, an electric lamp is only a special place on the route of an electric wire, and similarly a nerve-cell has its connections. They grow not from the nucleus, but from the general protoplasm of the nerve-cell. The nucleus has no textural connection with the processes of the cell, but we know that if these processes be at any point separated from the body of the cell and the nucleus they forthwith die. Thus the nuclei of the nerve-cells have a trophic influence upon the processes of the cells, as they have through those processes, or nerves, upon all the tissues of the body.

The changes made in the nerve-cells by muscular exertion

When we stain the nerve-cell in a special way we find that it contains a number of stainable, spindle-shaped lumps of something, which are certainly no part of the living protoplasm of the cell, but yet are a normal part of the cell as we see it. It has further been found that if an animal be allowed to exercise itself, or if nerve-cells be otherwise made to work, the nerve-cells involved, which can readily be examined if the exercised animal be killed and sections made of the appropriate part of the brain, are now almost wholly deprived of these so-called "Nissl's granules". We can only believe that they are a store of nourishment for the cell, which it uses when it is discharging energy; and their disappearance after work helps us to understand the profoundly important nervous element even in what looks like purely muscular fatigue. After a period of rest these granules are reformed in and by the cell; and we can scarcely help instituting the just comparison between what we see here and the case of the specks of pro-ferments found before, but not after, meals in the secreting cells of the digestive glands.

What may be seen in the photograph of a nerve-cell

The real protoplasm of the nerve-cell, apart from that of the nucleus, has lately been found to be of a most peculiar kind. There is very little of the ordinary protoplasmic network of a cell at all. On the contrary, we find what is shown in the photograph here reproduced. The body of the nerve-cell chiefly consists of fibers which run to it or from it, according as we like to consider them, and which simply run through the body of the cell from one process to another, if the cell has more than one. Indeed, these processes are cardinal parts of the nerve-cell; and the fibers which they contain and consist of are really the astonishingly specialized protoplasm of the cell-body itself.

Thus, in short, what we call a nerve, such as the ulnar nerve, or "funny bone", behind the elbow, is essentially a bundle of fibers which are really the extended protoplasm of a great number of nerve-cells. These fibers are found together in bundles, are covered with a kind of insulating sheath, and so forth, but essentially they are the projected portions of the protoplasm of nerve-cells, just like the projections thrown out by the amœba, or the cilia of ciliated cells. We now understand why the part of a divided nerve which is no longer continuous with the nerve-cells from which its fibers sprang must degenerate. Those fibers are really in just the same case as a piece of an amœba that has been cut away and is no longer sustained in health by the nucleus.

The processes of nerve-cells are of two kinds, and different cells vary widely in the number that they possess. The most important one is called an axone; and every nerve-cell that has not utterly degenerated must possess an axone, for by the axone alone does it give messages or orders.

A nerve-fiber not only conveys impulses, but has a life of its own

The majority of nerve-cells, perhaps, have only one axone. Some, called bipolar cells, appear to have two axones, one coming from either end of the cell, but only one of them is the axone.

But these cells, however, show, as a rule, a very large number of other processes, called "dendrites". These do not form nerves, and do not extend far from the cell they belong to. It is supposed that their function is to pick up impulses like the antennæ of a radio set. They are said to be withdrawn into the cell during rest or sleep, but we cannot be sure of this. In advanced alcoholic or other poisoning of the cell, and also in senility, the dendrites degenerate in varying degree and may become broken up. This may be the consequence of the degeneration of the cell, or the cause of it — if the dendrons are the "feeders" of the cell. In brief, these dendrites convey impulses to the cell body itself which in turn transmits these impulses to other cells via the single axone.

But the details of the nervous system are for future study. Meanwhile, we must look at the properties of a nerve-fiber, now that we know its nature. It conveys what we call a nerve-current, or nervous impulse. Any given fiber can convey impulses in only one direction. In an ordinary "mixed nerve", such as we find in a limb, there are many fibers which proceed from motor nerve-cells, and many which proceed from, and convey impulses to, sensory nerve-cells. But each fiber obeys the law of its own nature, and the current in each fiber is undoubtedly insulated from all the others.

The details of structure of a nerve-fiber may be studied at length, and certain varieties of type may be identified. These differences are trifling; and the essential fact is that a nerve-fiber is a living thing, made of specialized living protoplasm, part of the body-protoplasm of the nerve-cell.

The function of the nerve depends upon its life. It may die, or be poisoned, and will convey nothing however it be stimulated and though its material continuity be unbroken. Nerves can be removed from a freshly killed animal and kept alive in "normal saline" or other fluids for a long time, and their behavior can be tested directly, and by observing their influence upon the attached muscle, if it be a motor-nerve that we are studying. We thus learn that a nerve-fiber is alive, and therefore behaves like living protoplasm. It is of simple type, however, and is almost inexhaustible by repeated stimulation — very unlike the cell from which it proceeds. When it is stimulated an electric current is always produced within it, and passes along it.

The nerve-current not electric, though electricity stimulates nerves

Naturally, we suspect that a nerve-current must be an electric current. This is not so. The nerve-current moves along the nerve not at the stupendous speed of electricity, but at rather rapid speed. In a frog's nerve it has been found to travel about 28 meters per second; in a human nerve the rate is estimated at about 120 meters per second. It is a change in the living protoplasm of the nerve-fiber, and it is instantly stopped when the stimulus ceases, so that the process can be at once and indefinitely repeated. There is no end to the possibilities of inquiry here, for all manner of drugs may be tried upon all manner of nerves in different animals; and we find that some substances excite motor-nerves, some excite sensory nerves, and electricity is a stimulus to all kinds of nerves. Cold lowers the excitability of nerves in warm-blooded animals, and moderate heat raises it.

When we trace nerves to their ends we find a variety of structures. The end of a motor-nerve is called an "end-plate", a kind of spreading out of the tiny fibers of the nerve so as to cover the greatest possible surface. The end of a sensory nerve may be a great variety of structures, according to whether we are studying touch or vision or smell, or what not. But a very large number of nerves, arising from cells within the central nervous system, never leave it. The axone of any nerve-cell of this kind travels a long way, perhaps from one side of the brain to the other, or from the brain to the spinal cord, or in many other directions.

Instead of ending in a muscle fiber or in some sensory organ, it breaks up and spreads itself out, and practically *embraces the body of some other nerve-cell.* We observe, then, that this vast collection of nerve-cells which we call the central nervous system is indeed a system, and not merely an aggregation. Nerve-cells not merely control other kinds of cells, but they control other nerve-cells. And when we survey the central nervous system from this point of view we reach a great new conception, which the world owes to the famous physician, Dr. Hughlings Jackson, who died in 1911, and after whom is named "Jacksonian epilepsy".

Dr. Jackson saw that the central nervous system is made up of various levels, essentially three in number, of which the lowest is the oldest in the history both of the race and of the individual, the middle level coming next, and the highest level last; and the middle level can largely control the lowest, while the highest can largely control the other two. Each level has its own characteristics, the lowest being concerned with the merely animal life of the body, the next with the simpler emotions and managements of the body, and the highest being the seat of the essential part of man. This great doctrine is now accepted everywhere; and with the statement of it our survey of the nervous system as a whole is complete. Our next concern is to ascertain how this system behaves in practice.

RIGHT KINDS OF EXERCISE

THE HARMLESS PLAY IN SNOW WHEN CLOTHING IS ADEQUATE

THE PLAY-HOUR IN THE GROUNDS OF A CITY'S OPEN-AIR SCHOOL

WRONG AND RIGHT EXERCISE

Dangers and Advantages in Athletics —
How to Strengthen Without Injuring the Body

TRUTHS AND FALLACIES ABOUT EXERCISE

THE evil results of over-athleticism in schoolboy and undergraduate days has so often been called to the attention of the public that it should now be thoroughly warned against these dangers. The necessary reaction against this long-continued excess is now beginning to be in evidence; and we may therefore confine ourselves almost entirely to the discussion of the science of the matter which, particularly, is of very high physiological interest.

In our present analysis and explanation of the evils of over-athleticism, we shall definitely divide them into two categories — physical and mental. It has already been argued that, for the philosophic hygienist, the influence of anything whatever upon the mind must be the final criterion. Yet even for those who do not admit so much, and who argue that not only the first, but also the last, need is "to be a fine animal", let it be noted what a very unsatisfactory kind of animal over-athleticism produces, quite apart from any injury to the mind. The methods of physical development which ruin the most essential parts of the physique, from the heart onwards, surely stand self-condemned. The truth is that even physical exercise requires to have brains put into it, unless its own ends are to be defeated.

Most of the voluntary muscles of man are almost daily becoming less important, as modern invention supersedes them. But certain of the involuntary muscles retain, and must always retain, their primeval importance. Of these, the foremost is the heart, far and away the most important muscle in the body.

The remarkable lack of brains in modern notions of exercise, so unlike those of the ancient Greeks, is nowhere better illustrated than in the pre-war drill regulations of the British army, wherein no end of trouble was devoted to enlarging the size of the soldiers' chests. A series of disastrous exercises was invented, which made the chest abnormally rigid in a state of sham expansion, which evolved very serious strain upon the heart. After many years, when many thousands of recruits had had their hearts damaged more or less permanently by this absurdity, the regulations were altered. But they remain as an admirable illustration of the wrong type of physical exercise.

The whole and only value of the chest is that it shall be mobile. Its value is not in its absolute dimensions, small or great, but in the difference between its maximum and its minimum dimensions — a difference which physiologists term the "vital capacity". As we get on in years, the chest always slowly but surely enlarges, owing to the gradual loss of the elasticity which should restore it to its smallest size in the course of each expiration. This ultimately leads to stagnation of air and blood in the lungs, and strain upon the heart.

But if this be the kind of evidence which we find when we study the young man, what shall be said of the evils of over-athleticism in the growing boy? Here, of course, the evidence is not merely similar but still more serious. In some of our modern girls' schools the great effort is to imitate boys in every particular, to play all boys' games, and play them hard, often without proper adaptation for the girl.

Inquiries show the cult of athletics in some of our boys' schools often has the most serious and lamentable physical results, even for lads who are certainly not overtaxed in any other way, who live in pure air, and have plenty of nourishing food. If this be so for boys, it must certainly be a still more serious risk for girls.

The fallacies of the popular proposition that change is rest

As always, a competitive system of this kind is judged by those who set the pace for the others, and can stand it. Naturally endowed with fine physique, they are regarded as splendid products and illustrations of the value of the system — which is not even true; and nothing is heard of the much larger number who, in the endeavor to keep up with these few, have been more or less seriously injured, often for life. A powerful and very necessary reaction has taken place against these excesses, which begin by denying the first fact of all life — that individuals vary in natural capacity and cannot be subjected to uniform treatment without injury to many.

It is a very evident and important truth that "change of occupation is rest", but it is a truth that requires more accurate analysis than it usually receives. It has been most egregiously worked to death in connection with athletics. Those in charge of the young of both sexes have worked on the assumption that brain-work and physical exercise are wholly independent. It has been seen that the boy who was tired out with books and figures was yet quite evidently fresh and fit for keen activity out of doors when he was released. We may freely grant that change of occupation is the best rest in such a case, for the sufficient reason that the muscles of accommodation in the eye, many parts of the brain, and certain groups of body muscles, formerly hard worked, now receive absolute rest. They alone were strained, and now they rest — the formula about change of occupation means no more, in such a case, than that very simple proposition.

But next we have proceeded to assume that our formula, which really means so very little, works in the other direction. After physical exercise, the young people are set to brain-work again; not only young people, indeed, for thousands of brain-workers have tried the same plan with themselves. But in point of fact it does not work at all. Especially does it fail when the physical exercise has been something in a gymnasium, under the direction of a stern disciplinarian.

That is an extreme case, but what we are stating is true, in its degree, of all cases where the physical exercise really involves any fatigue. The fact is that real physical exercise of any kind involves fatigue; and no sooner does the physiologist study fatigue than he learns that this is a bodily condition which has a definite physical basis, and directly bears upon the working of the brain.

Professor Angelo Mosso, of Turin, in his "Fatigue", showed that it has a physical, or rather chemical, basis, consisting of poisons or fatigue-toxins produced by muscles involved in the exercise, and conveyed by the circulation of the blood and the lymph to all parts of the body, including the brain. It can be shown that hard work of the legs tires the arms, simply by distributing to the arms a proportion of the fatigue-toxins produced in the exercised muscles of the legs. This, of course, would not be so if fatigue were merely exhaustion of nutriment or energy supply in the muscles. More recently, those who have followed Mosso have shown that what athletes call training is mainly, if not wholly, a method by which the body acquires, through exercise, an immunity against the fatigue-toxins, just as it acquires immunity against many drugs, and against the poisons produced by many forms of disease-microbes. That doubtless explains the fact that modern trainers, even before prohibition, absolutely interdicted alcohol to their charges, for the experiments of Metchnikoff show it interferes with production of immunity to forms of disease-poison, doubtless by its retarding influence upon the action of those ferments in the body which produce the anti-toxins or antidotes to the poisons; and a similar action no doubt is effected upon the response of the bodily chemistry to the formation of fatigue-toxins.

The reason why vigorous exercise impedes the working of the brain

This conception of fatigue as toxic, which is no longer a speculation, but a definite result of modern physiology, must never be forgotten when we deal with the problems of physical exercise, and we must beware of applying the theory that "a change of occupation is the best rest" without discrimination. After hard physical exercise the whole body needs rest, because it is being flooded with fatigue-toxins. Even digestive rest is required, for very often if a hearty meal be taken during severe fatigue, it is found that the digestive organs, which were not themselves involved in the exercise, nevertheless behave as if they were exhausted.

Brain-work, however hard and intense, involves the production of only very minute traces of chemical waste products, far too slight to effect any influence upon the motor apparatus. Hence, the familiar doctrine already quoted happens to be right when the transition is from brain-work to physical work, and wrong when the change is in the other direction. Already in the regimen of the young, these important physiological findings are being attended to, and wise adults will soon begin to attend to them on their own account. The work of young people must be so arranged that the severest forms of brain effort, above all the actual acquirement and digestion of new knowledge, shall be attempted *before* the chief physical exercise of the day, and not after it. The competitive idea in our present sports and physical exercises for young people of both sexes requires very severe pruning.

We are not here speaking of games, but of athletic exercises and competitions and displays. The risks, then, which are more conspicuous in such athletic exercises as long-distance running races for growing boys (whose sprints should never exceed, say, one hundred yards), may also extend even to quite desirable games if certain precautions are not taken. There is a definite risk in any game where girls are seriously urged to measure their physique against that of boys.

Conditions under which vigorous sports may become harmful

It is absurd that children of either sex, when playing grown-up games, should be expected to imitate the conditions which suit strong men in their middle or late twenties. If 60½ feet for the distance from the home-plate to the pitcher, and a certain number of ounces for the ball, are right for adult baseball players, it is egregious that a youngster of thirteen should be expected to pitch the same distance with a ball of the same weight. A lighter ball, not quite so tightly wound, and therefore not so hard, and a distance of even as little as forty-five or fifty feet for small boys, will improve the game for them and be much safer.

Similarly, in games like hockey and football, the periods of play should always be many minutes shorter than those prescribed for adults, and the area of the playing-field should be much smaller.

As regards the adult's regulation of his own exercise, medical men are only too familiar with the carelessness and strange lack of reason which so often bring disaster in their train, above all to the muscular tissue of the heart. If we define as violent exercise that which causes us to become "out of breath"—an intensity which, of course, varies with the individual—then we must further note that violent exercise, thus defined, always means that serious, though not necessarily excessive, demands are being made upon the muscular tissues of the right ventricle of the heart. It is always the right ventricle that bears the brunt of exercise, having large quantities of blood poured into it, and being required to force them, at a great pace, through the lungs for the oxygen which the tissues are so rapidly using up; and the wall of the right ventricle is relatively thin.

But not all exercise that makes us out of breath is to be avoided. So long as the ventricle, stretched by its efforts, will return to its normal size in a few hours, we need not fear, but the exercise which produces dilatation not so quickly and completely recovered from is very danger-

ous indeed. Tapping the chest, or throwing Röntgen rays through it, will demonstrate that, when a schoolboy, or even a trained athlete, runs a hard quarter of a mile, the right ventricle dilates, under the pressure within it, to such an extent as an inch or more; and it may often be twenty-four hours before it resumes its normal size.

There are two ways in which the heart responds to excessive exercise. In some cases it enlarges in response to the need, and certainly that "compensatory hypertrophy" is the best that it can do. But though such hypertrophy, in the case of an ordinary muscle, involves no risks, in the case of the heart it is a source of future danger, however necessary at the time.

The muscle that matters most and is the most ill-used

The blood-supply of the heart-wall is inexorably limited by the caliber of the arteries which supply it, and the last state of hypertrophy of the heart is inevitably fatty degeneration of the overgrown muscle. Sooner or later the fatty heart must yield to the pressure within it, for fat cannot contract, and is not elastic. In the second group of cases, the heart does not begin by making the response of hypertrophy to overexercise, but dilates at once, and remains dilated, and thus is necessarily inefficient in one way or another, for mechanical reasons.

Mere overstraining, or temporary overdevelopment, of the muscles of the limbs matters little, and even damage done to joints usually matters little more, but damage done to an organ like the heart is vitally important.

The knee-joint is liable to serious trouble from over-exercise. This is the largest and most complicated joint in the whole body, and very easily injured when it is subjected to certain forms of strain. Often it is the "internal semilunar cartilage" of the joint that becomes displaced, and in many instances nothing but surgical removal will relieve the patient's disability. True, natural movement of this joint, as in walking or running, is not to be feared, only oblique and sidelong strains such as occur in football and certain kinds of jumping. Anyone whose joints and bones are constructed lightly and delicately should avoid such risks.

Now, if the foregoing arguments and the doctrines discussed in the preceding chapter mean anything, they certainly unite in condemnation of the foolish "Cult of Muscle", with which we must now deal, for it is perhaps the best illustration of exercise of the wrong kind.

The muscle-making craze an exercise of the wrong kind

By the cult of muscle we mean simply the much-advertised craze which teaches, in effect, that there is nothing great in man but muscle; that to be a good animal is everything; and that we must develop every muscle to the utmost. No serious student of anatomy could listen to such nonsense, for the study of the muscular system of the human body shows at once that it has many and widely distributed survivals of organs and muscles, which have nothing to do with what are now the habits of man. They do not even serve him if he wishes to excel in games, for his games, as we shall see, are based upon the characteristics of skill and coördination, and not nearly so much upon the high development of any special muscles or groups of muscles.

But the cult of muscle, like cults in general, is highly profitable to its chief exploiters, who include some very enterprising and skilful men of business. The theory apparently is that, having defied for years together the most elementary and cardinal principles of ventilation, cleanliness, exercise and diet, you may make good the damage by physical training and enlargement of the muscles.

It is deplorable to find how many people accept the cult of muscle in this preposterous fashion. Whether or not a spiritual paradise may be won by a deathbed repentance after years of evil-doing, certainly a physical paradise is not to be won by a belated and disproportionate and spasmodic attention to one of the minor laws of health, after years have been spent in defiance of the primal and unescapable laws of man's physical being.

How science and our feeling of fitness alike condemn artificial exercise

Man's adaptation to his environment is chiefly nervous and mental. His body contains numerous and important "disharmonies" between his physical constitution and his present vital needs. The voluntary muscles are really the end-organs of certain kinds of nerves called motor, existing for the execution of *purposes*, and it follows that the muscles for which the nervous system and the will have no purpose are simply a burden.

This single consideration gives us a very useful, practical criterion at once. The modes of exercise which could not possibly effect any purpose, but simply contort the body, or practise one isolated part of it as if it were a machine, are self-condemned. Either they are developing muscles which are not worth having, or else they are effecting a disproportionate development of some part of the body at the expense of the rest, and of the purposes of the whole.

The demands that muscle-making imposes on the various vital organs

A muscle is a living organ of great inherent vitality. It consists of very active living protoplasm, highly unstable, and needing a generous measure of nutriment. A healthy muscle, in a state of "tone", is always consuming food and producing waste products, in proportion to its bulk. The highly muscular man, developed by one of the new "systems", requires much food, and throws a heavy burden upon his digestive and excretory organs. If muscles are to be maintained at their largest, they must be constantly exercised; and not only does this mean a higher demand upon the organs of digestion and excretion, but, as we have seen, it involves the poisoning of the brain, as well as the rest of the body, by the fatigue-products of muscular exertion. Thus the brain has to pay a double price for the devotion of the bodily resources to the muscles. Large meals involve a large blood-supply to the stomach and the rest of the alimentary canal.

The right relative positions of brain-work and physical exercise

This, again, always means the relative starvation of the brain, and shows itself, after a meal, in the torpid or sleepy condition of most large eaters, or of a smaller eater whose blood-supply is not quite adequate.

A considerable degree of relative starvation of the brain must therefore be added to the temporary and slight but very effective poisonings of it by fatigue-products in the case of the man who lives for his muscles.

The value of exercise is not at all that it makes us muscularly stronger, with the consequent necessity of having to devote a higher proportion of our vital energy to the muscular upkeep.

The familiar confusion between muscularity and vitality

It is valuable for other purposes; and in our discussion of the various right kinds of exercise we must keep those other purposes in view. Few who grumble at the necessity of taking exercise, or who simply decline to take the time for it, will realize that the special and sufficient reason why they need so much is that they persistently eat too much. So long as they do so, they must take much exercise, which, in part neutralizes the effects of their over-indulgence. That is obviously a reason and a function for exercise which should not exist.

And, again, it is a delusion that exercise, and high muscular development, make us resistant or "strong" in all directions. That is the old and familiar error of confounding muscularity with vitality. The two things are utterly different, as we realize when we compare the relative resistance of the two sexes to starvation, hemorrhage, poisoning or cold.

Further, "training" really means the acquirement of immunity to fatigue. But all immunity to toxins is specific; vaccination only protects against smallpox, not against mumps or chicken-pox, and so on. Similarly, one may become immune to the fatigue-toxin, but helpless before others.

The right kinds of exercise: why play in the open air is ideal

If we hold fast by the principles already enunciated, we can now make speedy and certain decisions as to the right kinds of exercise, the health and healthy stimulation of the brain and of whatever serves the brain, for ourselves and others at any age.

The simplest form of exercise is that obtained in any moving vehicle in the open air. To the gymnast or the oarsman, no doubt, such a use of the word "exercise" seems monstrous. But it has now been proved that even riding in a carriage, naturally much more in an automobile which moves so much more rapidly, does actually stretch the muscles by a reflex action exerted through the nerves of the skin. No doubt this exercise is inadequate, but if anyone doubts whether it really be exercise, let him undertake a first ride in a wheel-chair "along the board walk," after grippe or appendicitis, and have his ride just five minutes too long.

Reflex action of moving air on muscles

The truth is that experiments made in the laboratory on the action of moving air upon the skin, and thence by reflex action upon the muscles, the glands, the production of heat and the processes of secretion, have given all students new ideas of the importance of the skin and of cutaneous stimulation. They have shown that the most expensive and elaborate systems of ventilation, such as are often employed in public buildings, which produce a perfectly pure and motionless atmosphere, are the worst that can be devised. In such a "dead air," as it has well been named, our skins lose an indispensable necessity for real health, during every moment except when we are asleep — namely, the stimulation of tiny, incessant blows, striking us in all directions, and dealt us by little currents of air. We say that a man wants a pin run into him to wake him up. Just so does the nervous system require the incessant tiny pricks of shafts of air if it is to work properly. Here, at last, is the kindest explanation of the "sleepy feeling" in church.

Supineness in the open air better than exercise in an indoor gymnasium

All this means that the various forms of exercise which consist, apparently, of no more than passive and effortless exposure to moving air — whether it moves past us, or we move through it, is, of course, immaterial — are being rehabilitated in the estimation of hygienists. And it is a clinching argument against indoor gymnasium work as compared to outdoor exercise.

Undoubtedly one of the valuable results of exercise is its promotion of full breathing, but deep breathing can really be of very little value unless it be the breathing of pure air. Indeed, if one had to choose between exercise in the ordinary indoor atmosphere and lying supine in the open air, it would be wise to choose the latter. Every indoor gymnasium, every system of developers and exercisers, is to be condemned if it keeps people indoors. There is no comparison, on the score of health, between the most elaborate and carefully thought-out system of indoor exercise, however complicated the apparatus and certificated the teachers, and the most informal stroll or scamper out of doors.

The value of a purpose beyond exercise while taking exercise

All exercise for the sake of exercise is a mistake — or, at any rate, a second-best. You may do your mind, and body too, more harm by sheer boredom than you may gain good from the exercise you go through. The dumb-bell is misnamed, for it shouts aloud the fact that the most elementary and obvious truths of psychology are still unrecognized, though the play and games of every natural child — if you object to being instructed by kittens — should be quite enough to teach us what, indeed, nature taught us ages ago, if only we would listen to her.

Everyone knows the difference it makes to have "an object" when one goes for a walk; and this universal and natural fact teaches us that we are not meant or constructed to take exercise for itself, but only to take it incidentally, without think-

ing about it, on the way to some end. The half-back who makes a touch-down benefits by the running, just because he is not running for running's sake, but to carry the ball over the line and help his side to win. In the new methods of therapeutic exercise for consumption, which are now in vogue at all sanatoria, the rule is to give the patients a piece of constructive work to do, with an end to aim at, and the fruit of their labors visible in front of them.

The best exercise, other things being equal, is the one we like the best

And so doctors are abandoning the indiscriminate ordering of mere "constitutionals" as such; they know more about the human constitution now. Walking is an inadequate exercise, in itself, for the reduction of weight in cases of obesity; and many walkers for their figures' sake have been disappointed in this respect. The great hygienic virtue of golf, so popular a game of many, is that they *find* it a game; and just because they have an object, they undertake the walking first, and the exposure to the open air second, which do them so much good.

The truth is that the best exercise, other things being equal, is that which we most enjoy, for happiness is the best tonic. Thus, though it is possible to generalize about the best exercise on the assumption that man is a machine, on any other assumption we must find out in the individual case what is enjoyed. But the enjoyment must be natural, and compatible with open air. Also, we must condemn all forms of exercise, whether or not the individual happens to enjoy them, which interfere with breathing. This entirely condemns weight-lifting and short races, where the runners are taught not to breathe at all during, say, a hundred yards sprint. The lungs are inflated, fixed, and only deflated when the race is over. This undoubtedly makes for speed, but it is exceedingly bad for the heart. The latest device is the inhalation of oxygen gas from a cylinder before the race, so that the expert may hope to be able to run even a quarter of a mile without deflating the chest, say in fifty seconds or less.

All this is vicious, and must be condemned without reserve. These are the kinds of practices which result in permanent dilatation of the heart, stretching and bursting of the ultimate air-cells in the lungs, and the allied evils which have led to the round condemnation of all spectacular, competitive sports by some extremists. To interfere with breathing is bad in itself, and it is bad for the heart, which largely depends for its health and its proper functioning upon the help it derives from the movement of the lungs.

But in health, for young and middle-aged and elderly, there is nothing like play. That is the verdict of modern physiology and psychology alike. Health and joy come from the attainment of skill, not of strength; skill, which is man's characteristic, rather than the animal strength which his skill has superseded and masters. In games we exercise not merely the muscles, but the senses; they are therefore educational for young people, in the profound sense, as other forms of "physical education", so called, are not. And the value of a purposeful movement made in a game is of a wholly different order from that of a not dissimilar movement which may exercise just the same muscles, for it involves the training of the neuro-muscular apparatus as an instrument of the will.

Much might equally be said as to the moral education, in discipline, self-control, judgment, unselfishness, honesty and so on, that are required in the finest playing of the finest games, but this will suffice. There are worse mottoes, for hygiene and for work, for life and for death, than "To play the game".

Athletic sports in America: are they or are they not overdone?

There has always been considerable discussion in this country, favorable and unfavorable, in regard to violent athletic sports, one group taking the stand that they are harmful, being a strain upon the nervous system and upon the heart; another group being equally insistent that they are beneficial and build up a sound physique.

Which of these is right? Neither is wholly so. It all depends upon the type of sport, the circumstances under which it is conducted, the physical condition of the individual, and his attitude of mind. Most harm has come, when any has resulted, from lack of training or over-indulgence. In the United States, for example, most injuries in football have occurred among high and preparatory school boys who have not been properly conditioned. Injury has resulted, not so much from the severity of the game itself, as from the condition of the player. Persistence in playing when not in good physical condition is the chief cause of trouble. Then, too, many young men participate in too many games demanding great exertion within too short a period. There are not sufficient rest intervals, and the strain upon heart and nerves is therefore too great.

The psychological element in the question of relative good or harm of sports

The psychological element is a very large factor in the question of the relative good or harm of sports. If a man engages in athletic games simply for the fun there is in them, and not primarily to win a victory or for a prize, it is usually most beneficial for his health. If, in competition for victory and for a prize, he trains under good advice for the contest and participates in it not too continuously, with a wholesome attitude of mind toward winning or losing, it should also be to his general physical advantage. But if the desire to win is exaggerated, if there is over-indulgence and lack of proper preparation, the results may prove disastrous. An athlete should never compete when not in condition. Overtraining is as bad as undertraining.

Biologically speaking, athletics sports *per se*, those involving running, jumping, throwing and climbing, are most beneficial. They use the different parts of the body according to their natural functions. This is not so true of gymnastics. The latter includes the use, frequently, of parts of the body in positions that are not so in accord, as, for example, supporting the weight of the body with the arms or hanging by the toes. The arms were not made to support the body and when they are used in this capacity frequently, the shoulder joints become restricted in movement, like the hip joint. Gymnasts often become "muscle bound". Games and plays involving natural movements are always the best.

Another advantage of athletic sports is their tremendous interest. They have a rich psychic content. To run, to jump, to strike, to throw, to climb, are absorbing pastimes. These activities make up most of our popular sports, like baseball, football, basketball and lawn tennis. They are movements which are as old as the life of the race. They have associated with them memories, perhaps unconscious, of the chase and the hunt. One loves to do them and for that very reason is often tempted to overdo them. One can go through calisthenics and gymnastics without excitement, but how different it is with sports and games!

The elements which, from a physiological standpoint, make the best games

From a physiological point of view, the best games are those which have:

First, the element of interest. There must be an emotional appeal. We engage in them because they are enjoyable. They must have enough variety in possible number of plays to appeal to the imagination and to the wits. This is the charm of baseball, lawn tennis and golf. We never know just what to expect. Each game has its surprises. If enough, the game becomes absorbing. We forget our worries. It relieves nervous fatigue. It proves stimulating.

Second, the element of competition. A match challenges to extra effort. If one can measure one's performance against a competitor, it adds to the exhilaration which comes from such exertion. Simply to go through physical movements without some such stimulus as is given by mild competition will not cause the muscles to contract so vigorously nor induce the exertion that is organically most beneficial.

OUT OF DOOR CITY PLAYGROUNDS

Courtesy Playground & Recreation Association of America

GROUP OF GIRLS IN A FOLK DANCE ON ROOF PLAYGROUND OF A NEW YORK CITY PUBLIC SCHOOL

APPARATUS FOR MEN AND BOYS AT SOUTH PARK, CHICAGO

BOYS' PLAYGROUND, BAMBERGER PARK, DAYTON, OHIO

Third, the element of variety of muscular exercise without prolonged strain and with frequent intermissions. This is highly important. Exercises of prolonged strain are dangerous. They increase blood pressure and produce muscle strain and temporarily interfere with breathing. Note how in weight-lifting the athlete's eyeballs bulge, his veins enlarge, his face flushes, his whole body is in a position of continuous strain. The safest type of sport is that which demands but momentary strain or effort, which calls for a wide variety of muscular movements and with intervals of rest. Take tennis, for example. Play is usually rapid, the movements sharp and quick, and separated by the longer intervals of picking up the balls and getting ready for the next serve.

Short dashes, like the 100-, 200- and 400-yard sprinting events, are good illustrations of athletic exercises which demand a tremendous expenditure of nervous and muscular energy. Fortunately, the duration is brief or the result would be exceedingly harmful. Long-distance running races, while tests of endurance, are not tests of strain like short dashes, except at the finish. They begin more or less leisurely. Strength is measured in advance and the pace set accordingly. A long-distance race is not, as a rule, as nerve exhausting as a short one.

If one were to attempt a classification of games with reference to their effects upon the nervous system and their physiologic value, we should find them ranking about as follows:

Photo Edwin Levick, N. Y.

HOCKEY — ALL ENGLAND *vs.* AMERICA — CENTER FORWARD PASSING TO OUTSIDE LEFT

Now these waits between are very important, physiologically, because they ease the strain and provide a period of brief rest. So, too, in golf, the time spent in looking for a lost ball is not lost time. In American Rugby football, the game is kept from being too severe by these same pauses while getting ready for the next play. In fact, the time spent in preparation probably exceeds that of actual play. A game of basketball may become a very severe test if the referee does not interrupt it by frequent calls of fouls. Vigorous, sustained play may be too long in duration. One of the valuable features of baseball is the recurrence of the innings, which provides for rhythmic periods of play and rest.

1. *Games and sports which are mildly stimulating:*

Throwing and catching a ball informally. Tossing a medicine ball from different positions. Pitching quoits. Archery. Target shooting. Bowling. Bowling on the green. Walking.

2. *Games that are vigorous but without nerve strain:*

Volley ball. Informal tennis. Non-competitive baseball. Cricket. Punting football. Riding. Noncompetitive running, jumping and weight throwing. Golf played without over-regard for winning. Boxing lightly for points. Tag games. Circle games. Hiking and walking at vigorous pace.

Photo Edwin Levick, N. Y.

FOOTBALL — HARVARD *vs.* YALE: A TENSE MOMENT IN FRONT OF HARVARD'S GOAL

3. *Games that are vigorous and require special training:*

Competitive baseball, basketball, volley ball (in tournament games), cricket, lacrosse, hockey, polo, soccer football, cross-country running, track and field sports, walking contests and long hikes.

4. *Games containing an element of strain and requiring endurance:*

Highly competitive basketball, football, lacrosse, hockey, boxing, wrestling.

5. *Games which are dangerous:*

We should place among the dangerous sports boxing, wrestling and American Rugby football. Only those in excellent physical condition and who have no physical or organic weakness of any kind should participate in any of these sports. Boxing is dangerous because a blow may be received at any time on a vulnerable spot and, in the latter part of a contest which is allowed to go beyond eight rounds, the participants may be so fatigued as to be peculiarly susceptible to injury.

Wrestling is a particularly dangerous game. It violates all the principles of wholesome exercise. The exercises are those of sustained strain and tension long drawn out. Wrestlers develop thick necks and big muscles and correspondingly large hearts. Young men should take up this form of exercise very cautiously and under competent advice.

American Rugby football is a dangerous sport because of the bodily contact, the tackling of the player when running at top speed, and the mass plays. The game has been opened up considerably and made much safer, but there is, because of the very nature of the game, likelihood of injury. It is not a game for boys of preparatory or high school age. Such boys play it to a risk life and limb.

Basketball is hard on the heart. Many teachers of athletics consider it the most serious in its effects upon the heart of any of the major sports. There is violent bodily contact and if the game is not well controlled, it produces serious results.

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THE DIFFUSION OF WORKING ENERGY

THE transmission of power is a wholly modern phase in a story of industrial growth. In the operation of the hand tools, alone used through untold thousands of years, the muscular power was applied directly to hammer, or chisel or saw. The first transmission in mills marked a momentous advance. The windmill or the water-wheel harnessed nature's forces, to be transferred thence to the spindles and stones a few yards away by wooden shafting, wooden cog-wheels and leather belts. When James Watt's epoch-making though crude steam engines were developed, the problem of transmission remained unchanged, still circumscribed by the mill walls. And thus matters stagnated right down to within the recollection of the present generation. Engines grew in size and power and efficiency. But still a big steam engine supplied power to a mill or factory to be transmitted through shafts and pulleys and gears. Even an extensive modern factory was until very recently just a magnified mill. Many are today. The only difference is that the transmission takes place through longer shafts and belts, and more of them, and by more powerful drives. And if the mill or factory happens to be exceptionally large, then more than one engine is installed, simply to avoid having to carry shafts and belts to inconvenient distances.

That briefly defines the system which held an apparently unassailable, and as yet unmenaced, position a quarter of a century ago and which, where vast sums have been sunk in plant and machines, must be retained in hundreds of mills and factories. But what a tremendous advance is made when the machinery of a factory can be driven, and the place can also be illuminated, by power generated at distances measured not by a few hundred yards but by many miles! That is an accomplished fact, beyond the wildest dreams indulged in when men now mature were young.

Transmission of power has therefore now two broad aspects, one being that where it is carried over long distances, the other over small areas. The first is the one which appeals more powerfully to the imagination, yet the second is of equal importance. The first concerns the supply of power to a mill or a factory or a city, or to groups of either. The second deals only with its distribution throughout a local area.

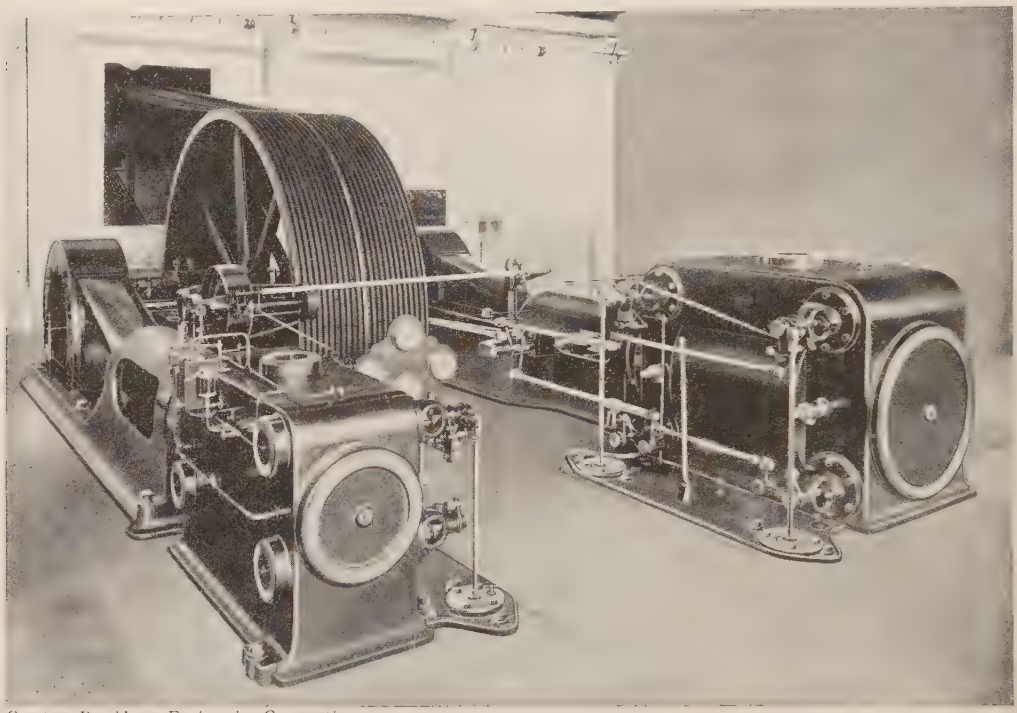
The great objection to the shaft, pulley and belt system of driving is the enormous proportion of power lost in friction. In the best equipped engineers' factories it is estimated that, for every horse-power given out by the engine, less than half a horse-power is available at the machines, one-half or more than half being lost on its way in the rubbing of shaft journals, in the clinging of belts, and the sliding of the teeth of toothed gears. And if these mechanisms are badly fitted, the losses will be 10 or 15 per cent greater. Even in a cotton-mill, which ranks highest in factory efficiency, the losses, though not so great, are serious. In one case it was found that a loss of 39 per cent was going on — an engine giving out 1252 horse-power to do 896 horse-power of work. If an all-electric drive is adopted for distribution instead of shafting, pulleys and belts, the loss is not nearly so great, being only about 10 per cent of the energy produced.

Let us glance at the sources of power which are commonly harnessed into service, and consider them from the point of view of their value as agents for transmission. These are steam, gas, oil, water-pressure, air and electricity.

Steam — a mighty storage of energy that has formed an exhaustless theme for so many pens in the past — is being rudely shouldered out of spheres where formerly it was unchallenged. The reason is that you cannot transmit steam more than a few hundred feet in pipes without the loss of much of its energy by the dissipation of its heat. Therefore, the steam generator — the boiler — must be near the engine, and the power given out by the latter transmitted by other agents: until recently shafting and pulleys, connected by leather belting, ropes or toothed wheels. With relays of these agents a very large factory can be served from one set of engines, but with a sacrifice of, roughly, one-half the power of the engine, lost in the friction of the transmitting elements.

Gas carries the problem of power transmission a stage in advance, because gas can be conveyed in pipes over distances measured by miles. But the gas must be cheap to compete with steam, and therefore city gas cannot enter into rivalry with steam. Only waste gas from furnaces or gas generated in producers from cheap fuel can sustain that rivalry. The field of transmission is extended, but only with a rather limited area.

Oil occupies much the same position as gas, because it can be conveyed in pipelines and stored for use. But neither it nor gas can help the problem of transmission very much, because in both cases the engine which transforms the latent energy of the gas or oil into active force is located, like the steam engine, in one spot, from which the power must be distributed by other means. A steam engine, or a gas or oil engine, can only do work directly over long distances by being attached to a vehicle, which is a development of a different character from that which we are considering.



Courtesy Providence Engineering Corporation

RUNNING A MILL BY MEANS OF A ROPE DRIVE

This is a 900-H. P. Rice and Sargent horizontal cross compound steam engine. The boiler pressure steam first enters the nearer high pressure cylinder. The expansion begun here is then completed in the larger low pressure cylinder. From there the steam passes to the condenser which makes it ready to enter the boiler again as feed water.

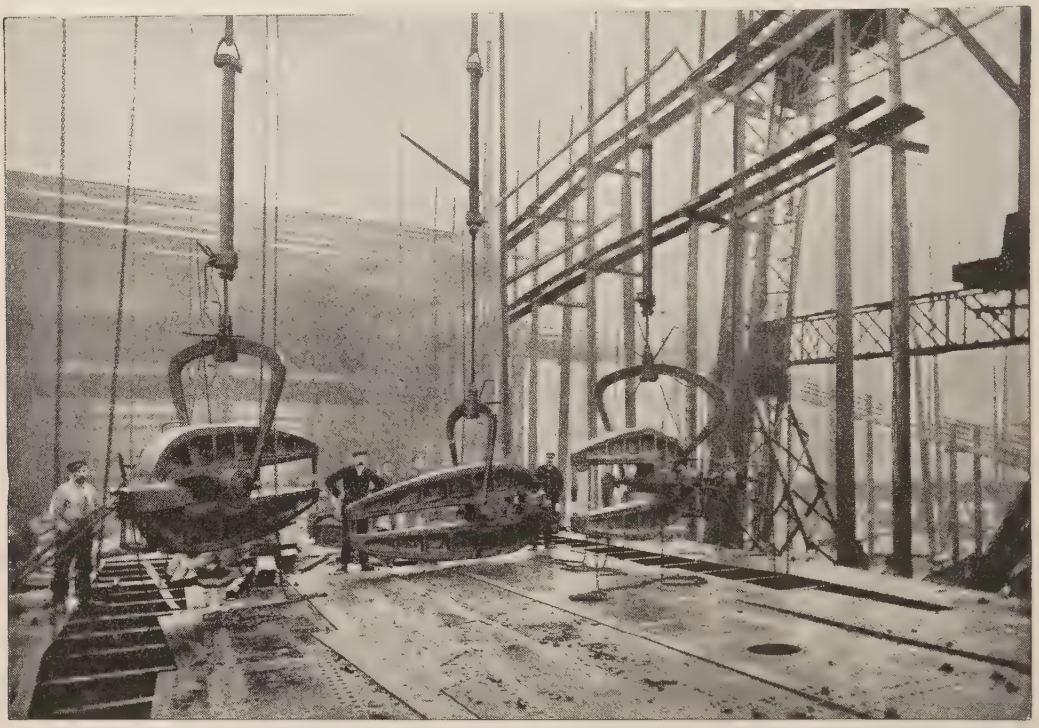
Akin to the steam, gas and oil engines are the turbine water-wheels driven by the pressure and momentum of water, due to head, of which we need only mention that the turbines differ from the old water-wheels in being more efficient — that is, they give out a larger proportion of the power latent in falling water than the old water-wheels did. These, however, drive shafting and wheels, etc., in the immediate vicinity, as do the other prime-movers. But, owing to electricity, the use of falling water now occupies a vastly larger sphere than of old. Apart from this last new agent, the employment of turbine wheels would inevitably have increased in countries where water-power is plentiful, and coal costly, but still transmitting power by shafting, pulleys and cotton ropes or belts. The electric cable, however, has increased the demand for turbine wheels to an extent far greater than this — so much so that in the districts where water-power is abundant no other form of motor is ever installed. Here the water is not the agent of transmission, but the electricity.

Power, however, can be transmitted by water-pressure alone, with scarcely any loss, to a distance of many miles. London has a network of 174 miles of hydraulic mains, which deliver 21,900,000 gallons of water from the Thames weekly to consumers at a pressure of 750 pounds to the square inch, and other English cities and many in our own country have similar hydraulic installations, though not as large.

WATER RAISED BY WATER — A HYDRAULIC LIFT ON AN ENGLISH CANAL

Water transmits its pressure practically undiminished, because it is nearly incompressible. Under high pressure it acts like a solid rod of steel, and the pipes have to be very strong to carry it.

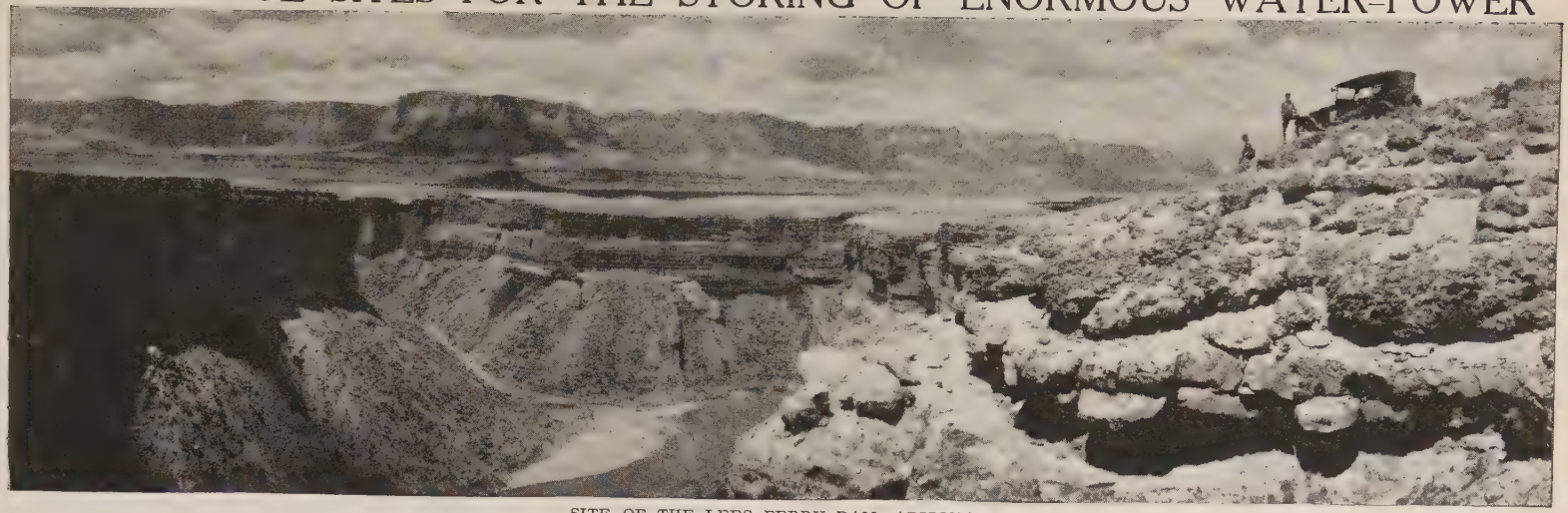
Though water-pressure can be conveyed thus for several miles, it is more often employed for lesser distances. It is used to transmit power to machines in workshops, and to cranes on quay walls. Most of the coaling of vessels is done by hydraulic cranes, worked by water conveyed in pipes. All steel ingots for guns and armor-plates are compressed by water-power, transmitted through pipes from pumps and accumulators. Every day, in every great center of industry and manufacture, thousands of operations are performed silently by massive machines actuated by water under pressures ranging from 750 pounds to four tons to the square inch. The heaviest engineer's work is done by this agent. A press at the Bethlehem Works in Pennsylvania exercises a total squeeze of 14,000 tons. Big dock-gates are opened and closed by water-power; swinging and lifting bridges, also, and much beside. Canal-lifts in England and on the Continent are worked by water-pressure, raising the barges from one level to another. An ingenious machine for moving water on a small scale is the hydraulic ram, by means of which a large quantity of impure water under a low head may be used to pump a smaller quantity of pure water against a higher pressure. Allied to hydraulic supply is that of compressed air. Conveyed through flexible pipes, it is much used for driving engineers' tools of various kinds. Many of these uses are in structural construction and underground work. Air under high pressure is carried for long distances, sometimes several miles, especially in mines and tunnels for both power purposes and ventilation.



HYDRAULIC RIVETING-MACHINES AT WORK ON THE DECK OF THE *OCEANIC*

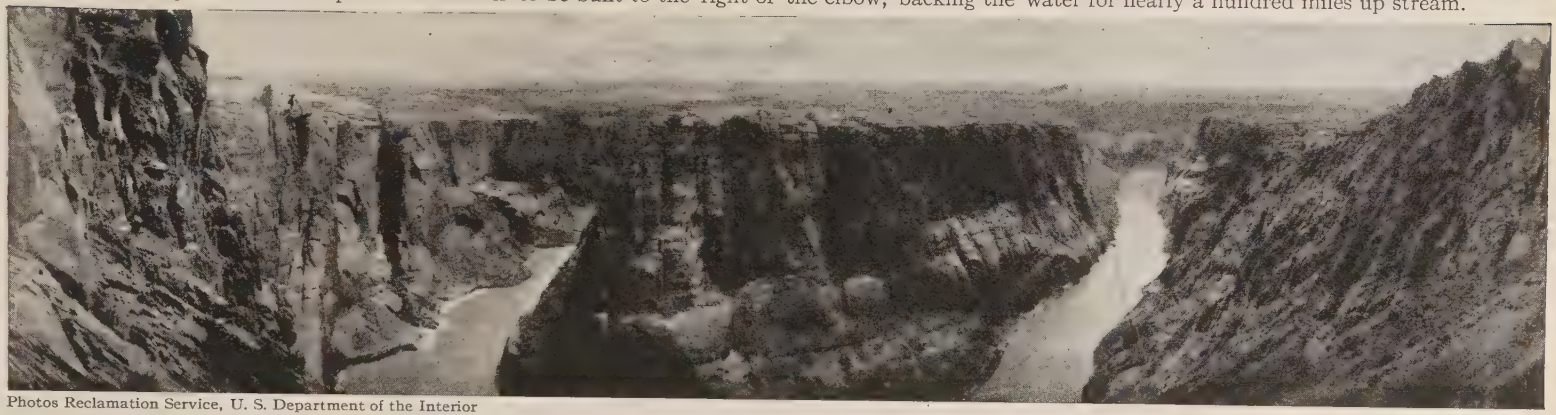
But electricity transmitted along stationary wires is the latest, and now by far the most valuable, agent of transmission. Its range vastly exceeds that of any other. It is a more flexible agent; and what renders it especially serviceable is the fact that every one of the power agencies which we have mentioned is readily convertible into electric energy on a rotating shaft. Electrical transmission has played a most important part in the development of water-power. Many such resources now available would be useless without long distance electric transmission.

WONDERFUL SITES FOR THE STORING OF ENORMOUS WATER-POWER



SITE OF THE LEES FERRY DAM, ARIZONA

The canyon makes a loop and the dam is to be built to the right of the elbow, backing the water for nearly a hundred miles up stream.

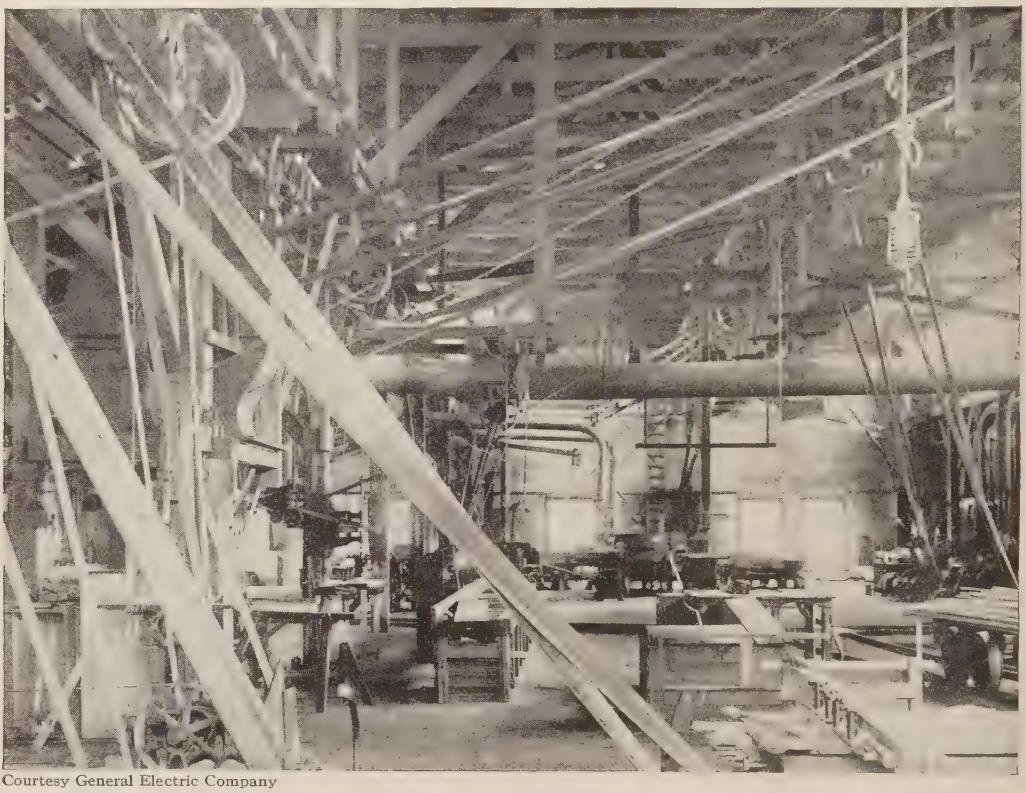


Photos Reclamation Service, U. S. Department of the Interior

MARBLE CANYON FROM THE MOUTH OF SOAP CREEK

Here, just above the Grand Canyon Reservation, which will remain untouched, is the location of an important power site in the Colorado River project.

Mechanical difficulties in the translation of either form of power into electricity can be surmounted; the only question that remains for engineers is an economical one — that of the relative cost of different systems. Local conditions largely determine the selection. In places where coal is cheap, steam engines usually have the preference, but large gas engines are better in the neighborhood of great power-stations that utilize waste gases from blast-furnaces and other sources. In Switzerland, southern Germany, France, Sweden, California and Canada, the water-turbine is supreme.



Courtesy General Electric Company

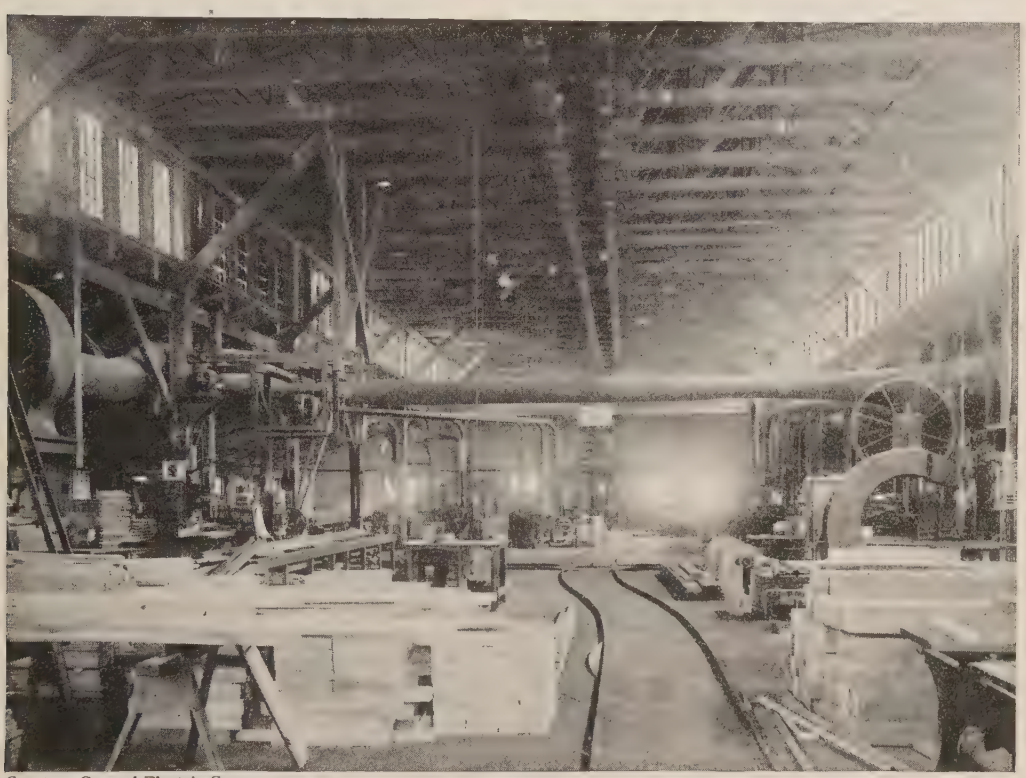
WOOD-WORKING FACTORY DRIVEN BY SHAFTS AND BELTS

Often the features of transmission to a factory or mill are reproduced within its walls. Then, instead of belts and pulleys and shafts, each machine has its own electric motor, driven by a cable from the main dynamo. But only in regard to the more recently equipped factories would this statement hold good. In many factories, shafts and belts, etc., have been reduced in number and their place taken by electric cables. Sometimes wholly replaced, but more often greatly lessened, small groups of machines are still belt-driven, but each group derives power from one electric motor. In practically all of the recently built factories, however, the full electric drive has been installed using the "one machine, one motor principle". Cranes, however, are an exception to this. A form of transmission of power akin to that of street railways and railroads is applied to electric traveling cranes, which may either run along on surface rails or on overhead tracks. Cranes of the latter kind will lift loads ranging from one ton to 150 tons by current conveyed along bare copper wires from any distance. These are located along the sides of the shop, and along the girders which carry the lifting apparatus — wires of three-eighths of an inch, or half an inch diameter only, yet charged with such enormous and helpful capacity!

The real era of long distance transmission began in 1893, when electricity, generated by water-power in Sweden, was sent ten miles, from the Hellsjön Falls to the Grängesberg iron mines. The plant of this significant experiment was of 400 horse-power capacity, and it is still in successful operation.

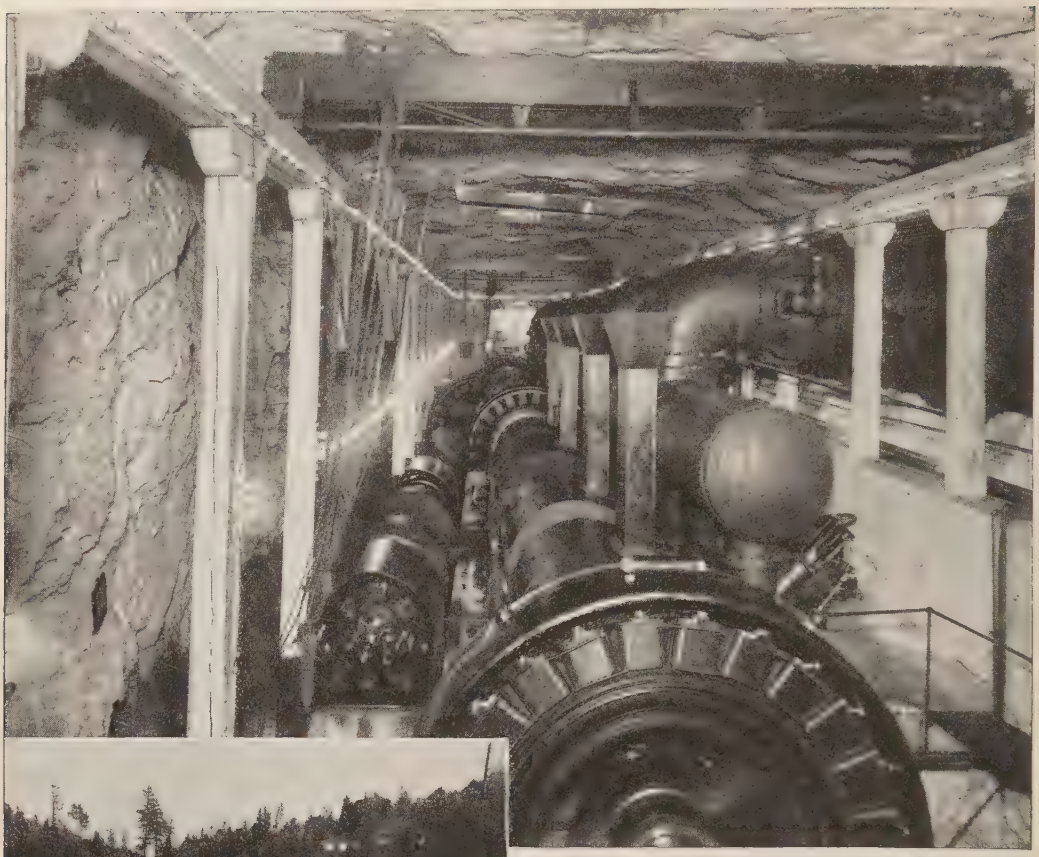
The hydro-electric power installations of Norway and Switzerland are numerous and wonderful, but those of California and the Pacific Coast generally are on a far vaster scale, and have been carried out in the face of greater difficulties by pioneers working in dense mountain forests where the ax has had to clear the way for the transmission wires. It is in these western wilds that the problems of very long distance transmission were solved, for San Francisco first, and afterward for other cities. Torrents there are in abundance all along the slopes of the Rockies. Cataracts and swift streams had run to waste since first the morning stars sang together, but many of these waters have now been harnessed to the service of man, and transmuted into light and movement. Always the agent is the cataract or stream, turning a turbine wheel, rotating a dynamo, and generating electricity, which the wires convey to the distant towns and cities.

Among the most remarkable of the installations in the West are the Snoqualmie Falls, in Washington, with a transmission of 83 miles; the Bay Counties of California, with 152 miles; and the Standard Electric Company, 154 miles. A part of the last used in connection with the Bay Counties has a transmission of over 220 miles. Startling and eerie are some of these installations. The Snoqualmie Falls are approached over a railroad that winds picturesquely up into the Cascade Mountains to the town, nestling in a setting of forest and gorge, and lighted by the waterfall. Here one must descend 270 feet below the surface in an elevator to reach the power-house, located in a cavern in the



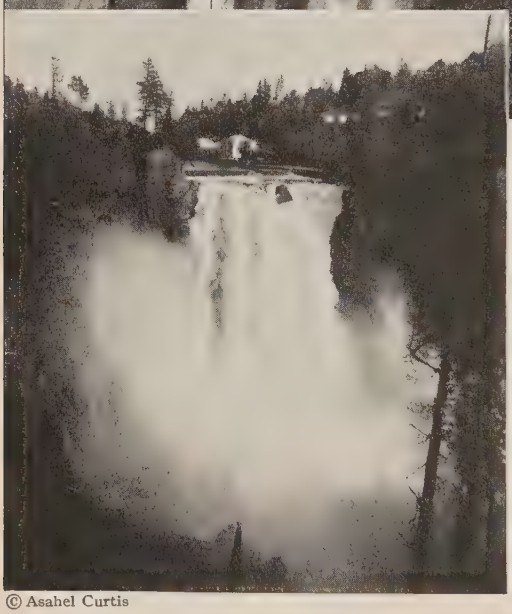
Courtesy General Electric Company

THE SAME FACTORY AFTER INSTALLATION OF ELECTRIC DRIVE



GENERATING STATION OF THE PUGET SOUND POWER & LIGHT CO.

Blasted and hewn out of the solid rock 270 feet below the upper level of the Snoqualmie River; a unique engineering feat.



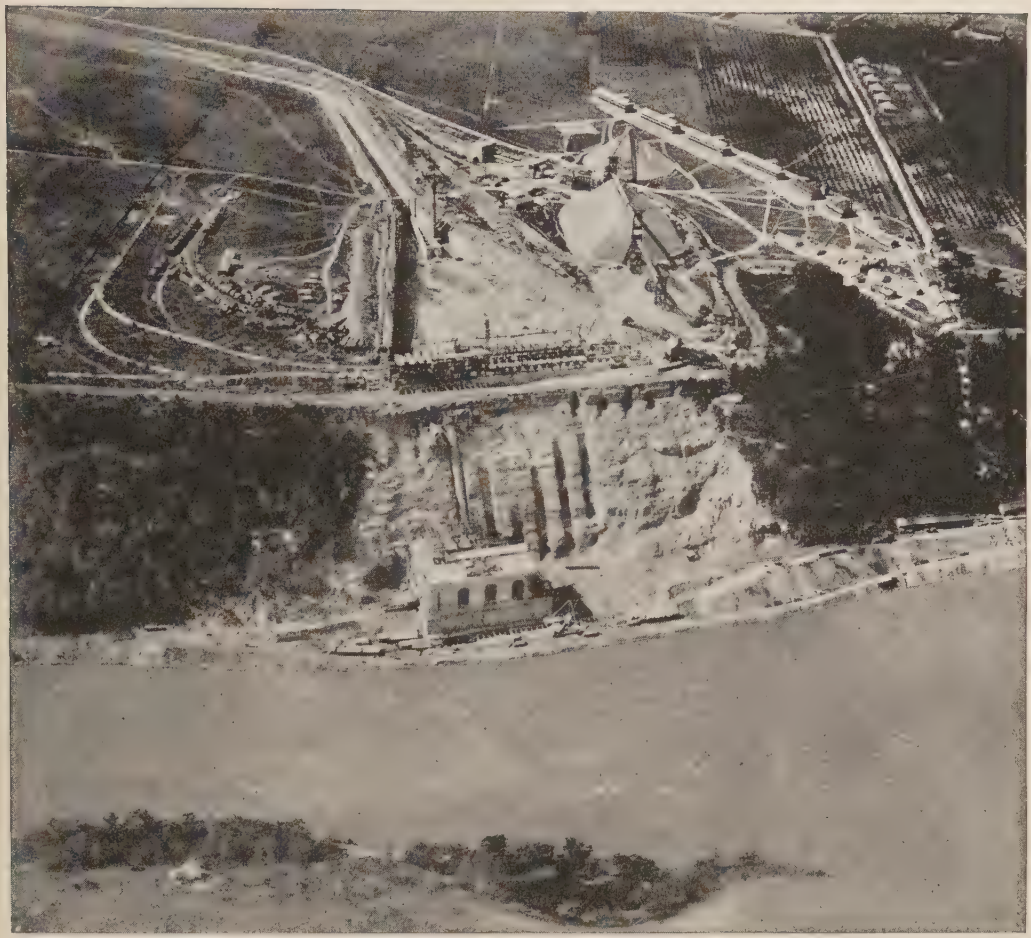
© Asahel Curtis

SNOQUALMIE FALLS

These falls, near Seattle, are 270 feet in height, or more than 100 feet higher than Niagara.

solid granite rock beneath the falls. In this cavern are six electric generating machines, and they are so placed as to afford protection to the machines from the everlasting spray from the cataract. Current is thence carried through dense forests of spruce and fir, a broad band having been cleared by the pioneers in order to prevent risk of trees falling on the wires and interrupting the service. This plant provides light and power for half a million people in two of the great cities of the Northwest—Seattle and Tacoma.

In California, especially in the southern districts, are canals from five to fifty miles in length connected to river rapids in the heart of the mountains, often far removed from human habitation. These convey the water under heads ranging from 300 to 1500 feet, to drive the turbines on the shafts of which the electric generating-machines are coupled. The Standard Electric Company has developed from an earlier scheme that of the Blue Lakes Water Company for supplying water to mines in Amador County. The company



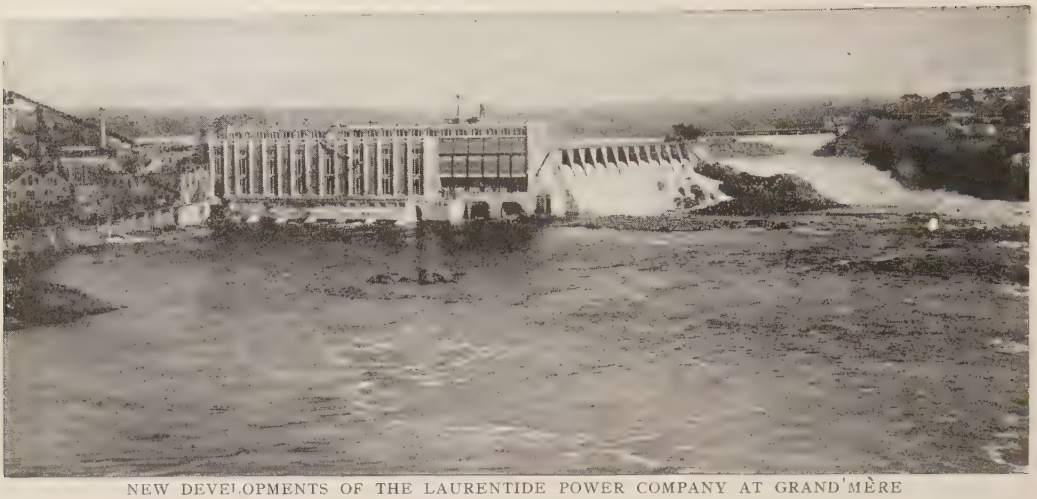
Courtesy *Engineering News-Record*

QUEENSTON-CHIPPEWA HYDRO-ELECTRIC POWER PLANT AT NIAGARA

Airplane view, looking across the Niagara River, at the partly completed power-house, showing the bed of the canal and the forebay of the 550,000-H. P. development planned by the Ontario government. The project takes water on the Canadian side about 1½ miles above the falls and delivers it through the Welland River (whose flow is reversed) and canal 13½ miles to the power-house under the bluff 5 miles below the falls. The plant is intended to supply the increasing demand for electrical energy of the cities, towns and rural communities of the district in southwestern Ontario extending from Niagara and Toronto on the east to Windsor and Sarnia on the west.

transmits power to San Francisco at 50,000 volts. The enterprise involved building storage reservoirs in the high Sierras, 6000 to 8000 feet above sea-level, provided with dams, and capable of storing a supply for 150 days, the maximum dry period in Alpine County. Thence the water is allowed to flow along 50 miles of river channel to a dam, where it is diverted into a canal 25 feet wide, 5 feet deep, and 20 miles long, to the crest of a hill over the power-plant, which it supplies with a head of 1450 feet! The water issues through a tunnel 3000 feet in length, at a velocity of 18,000 feet per minute, and turns wheels 11 feet in diameter at a speed at the periphery of 9000 feet per minute. Thence the current generated is carried through the city of Stockton, and the town of Mission San José, along the shores of San Francisco Bay to a distance of 100 miles from the power-plant. Here the wires diverge north and south, running north about 28 miles to Oakland, and south to San José, around the bay and up to the north to San Francisco, a distance of 154 miles from the generating station.

The Bay Counties Company operates a line 152 miles in length from its plant to the city of Oakland, the most remarkable feature being the crossing of the Straits of Carquinez with cables having a span



NEW DEVELOPMENTS OF THE LAURENTIDE POWER COMPANY AT GRAND'MÈRE

of over 4000 feet. The Standard Electric Company buys power from the Bay Counties Company, which they transmit, making a total transmission on the part of this company of 198 miles to San José, of 200 miles to Redwood City, and 218 miles to Stockton. These plants operate railroads, flour-mills, mines and lighting.

Among the projected power developments that which plans to use the waters of Lake St. John and the Saguenay River overshadows all others. When completed it will not only supply the growing demands of all of southern Canada but may have plenty to spare for northern New England as well.

The city of Guadalajara, Mexico, obtains its electric power from the falls of Juanacatlan, on the Rio Grande; and the city of San Luis Potosi is supplied with power from a generating station 200 miles away, by the Central Mexico Light & Power Co. at 100,000 voltage. The construction and maintenance of such a line in a wild country is one among the many great feats of the electrical and mechanical engineers. The lines must be high up above the ground, must traverse valleys and mountains and rivers. In winter snow and sleet will lie heavily on the wires and break them down if ample strength is not given in the supporting construction.

POWER PLANT AT SHAWINIGAN FALLS

The great power plants owned or controlled by the Shawinigan Water & Power Co. on the St. Maurice River have a combined generating capacity of 330,000 H. P., shortly to be raised to 600,000. They supply heat, light and power to the cities of Quebec and Montreal and many other smaller cities and towns of southern Canada.

JUANACATLAN FALLS FROM WHICH THE MEXICAN CITY OF GUADALAJARA OBTAINS ITS ELECTRIC POWER

But every increase in diameter and weight adds seriously to the expense of long lines. The hurricanes will blow the lines down, unless the poles are reasonably near together and well secured in the soil. Plain wooden poles are insufficient when the lines are very lofty. Steel poles are then used instead of wood, and sometimes steel towers. On the San Luis Potosi transmission there are 70 miles of these steel towers. Branches of trees falling on the line will short-circuit it, cutting off the current. Mischievous people will take aim at the insulators, or cut the wires and steal the copper to sell it. Because of these things a long transmission line is a cause of daily anxiety to the engineer in charge. It is necessary to keep men patrolling and inspecting the line, each in his own section, with houses for their accommodation. A safe method, but too costly for general adoption, is to have a reserve parallel line, not less than a mile away, in case of the temporary failure of the other.

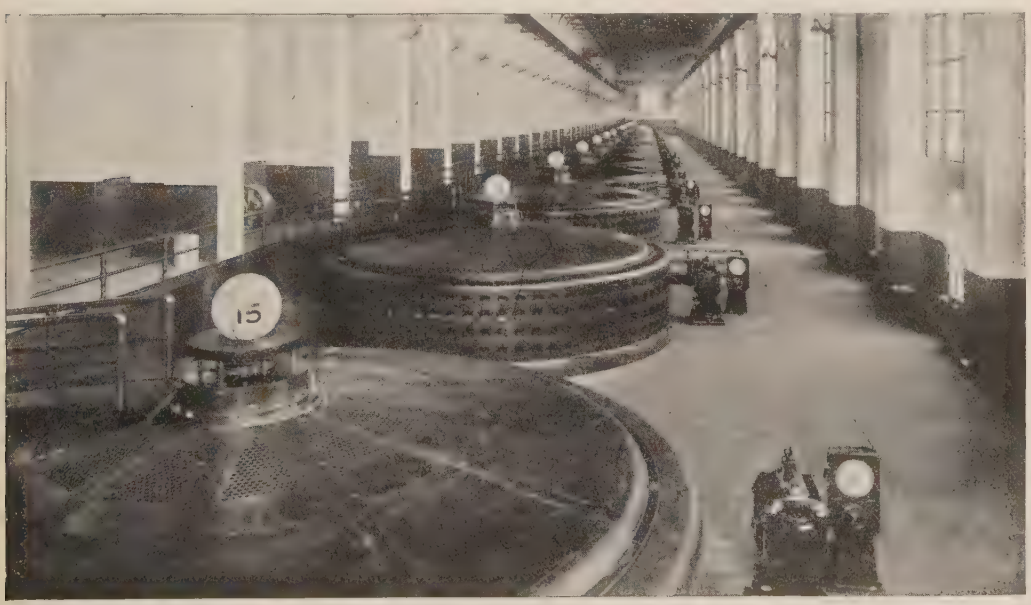


Photo Anschutz

TOPS OF THE ELECTRIC GENERATORS IN THE POWER-HOUSE OF THE 150,000-H. P. HYDRAULIC PLANT ON THE MISSISSIPPI RIVER AT KEOKUK, IOWA

Apart from such a provision, the failure of current would deprive thousands of service, stop street cars and plunge cities into darkness. And the conditions vary in different countries. Lightning is a danger in some, landslides and floods in others.

In transmitting power over long distances the voltage must be high, and then trouble appears, because high voltages find out weak spots. This is the reason why progress has been tentative, and apparently slow. Ten years ago no one imagined that voltages of over 100,000 would be common, with transmission to 240 miles. Now some electricians confidently anticipate voltage of 200,000 and distances nearer 400 miles — and this is not unreasonable.

Power from Niagara is now transmitted to Syracuse, 150 miles away, at 60,000 volts. Yet, when Niagara was first harnessed, the limit of transmission was Buffalo, only 21 miles away. When distances grow, the difficulties of insulation and other practical details become so pressing that it is often better that industries should migrate near to the source of power, or that new industries should establish themselves on the spot, than that very long transmission lines should be installed. This attraction of industries in the vicinity of the generating station has happened to Niagara, and to several other places in this country, and in France and Switzerland. It is estimated that Niagara has an energy of nearly 5,000,000 horse-power. An average of 222,400 cubic feet of water passes over the falls each second, equal to 25,000,000 tons per hour, or one cubic mile per week. Of this at the present time about 600,000 horse-power is laid under tribute, obtained by turbine wheels of from 5000 to 12,000 horse-power each.

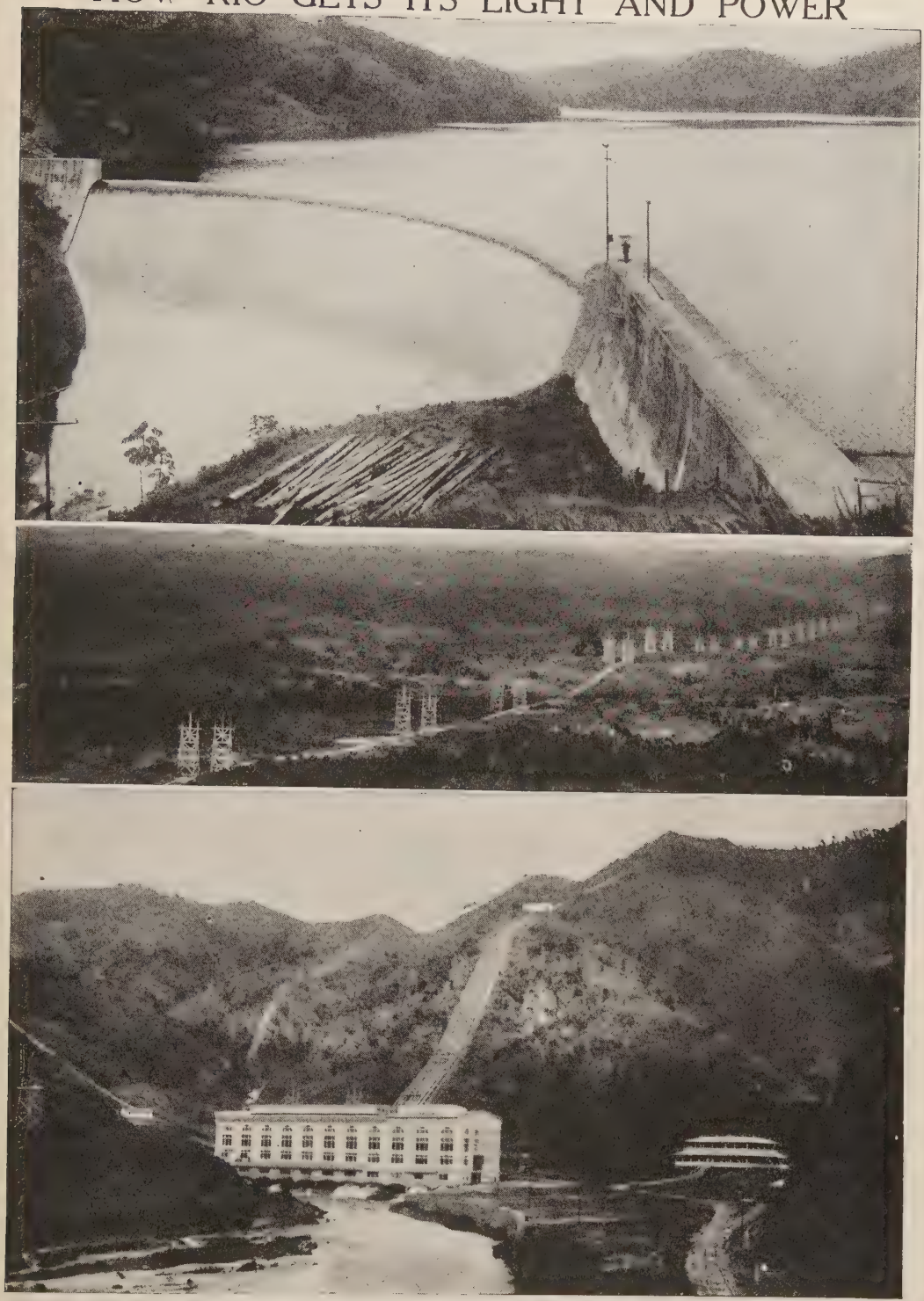
Rio de Janeiro, with a population of a million, is supplied with light and power generated 50 miles distant, 54,000 horse-power being transmitted, at a line-voltage of 88,000, which will be increased in the future. The electricity is obtained from six turbines receiving water from a vast artificial storage reservoir 17 miles long, having a total volume of 7840 million cubic feet. This water is obtained from the Lages River.

In France there is a 6300-horse-power transmission system which extends from Montiers to Lyons, a distance of about 112 miles. From an engineering point of view this is a remarkable example of long distance transmission by continuous current. It drives the street car system of Lyons, and feeds an existing system previously working there. Two overhead wires convey the power nearly all the distance, until, when within a few miles of the city, they are carried underground. At Molinar, Spain, there is a power scheme which transmits energy to Valencia and Alevy, over 50 miles; to Cartagena, over 100 miles, and to Madrid, over 150 miles. The pressure is 70,000 volts.

During the last decade great advances have been made in the development and improvement of hydro-electric plants. This is especially true of the turbines which utilize the water-power. These today are driven at double their former speed by the same head of water. The largest units now in operation are at the Queenston power-house of the Hydro-electric Power Commission of Ontario, where two 55,000-horse-power turbines are in service. When the plant is completed its total capacity will be 600,000 kilowatts.

Electric transmission has partially solved the acute problem of suburban railroad and street car traffic in New York, London, Paris, Vienna and other great metropolitan cities — so recent and yet so vast are its ramifications! Two English street railways, one in Liverpool and the other in London, aroused much interest about 1890, because they were pioneer works, precursors of electrically operated lines that link up the suburbs of the great cities with rapid service. Steam engines are forever ousted from these services, displaced by the invisible current that renders the electric cable or rails alive.

In countries where there is no water-power of sufficient size for commercial plants, engineers must make use of other sources, like the inferior fuels, gas, etc. Where oil is a cheap fuel, the efficient Diesel engine makes inexpensive power easily obtainable. This last is well illustrated in certain sections of the United States.

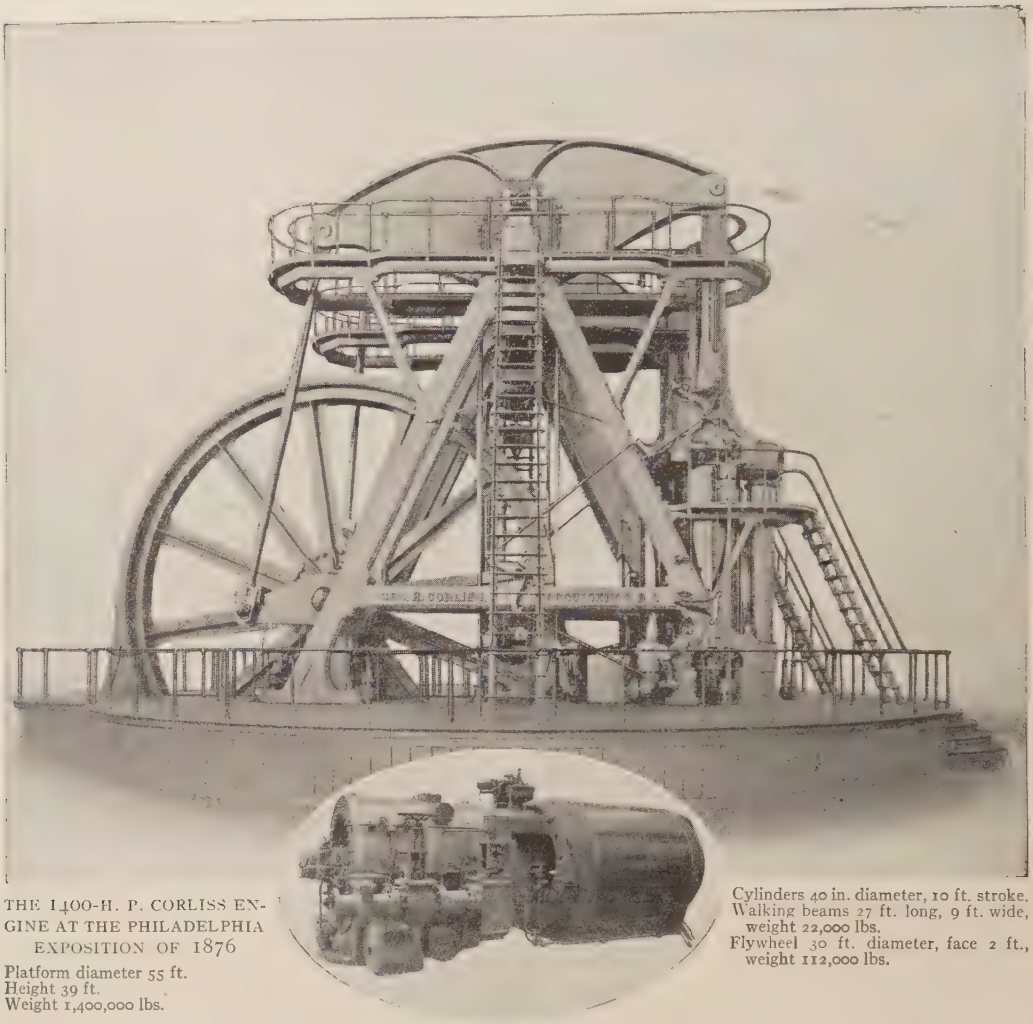


LIGHT AND POWER FOR THE CITY OF RIO DE JANEIRO

The dam in the Rio das Lages, 115 feet high and 705 long, built in a curve to better resist the pressure of the water in the 17-mile reservoir back of it, and set into the solid rock at each end and on the bottom.

The transmitting wires which carry the electricity 50 miles to the city.

The power-house where the transformation takes place.



THE 1400-H. P. CORLISS ENGINE AT THE PHILADELPHIA EXPOSITION OF 1876

Platform diameter 55 ft.
Height 39 ft.
Weight 1,400,000 lbs.

Cylinders 40 in. diameter, 10 ft. stroke.
Walking beams 27 ft. long, 9 ft. wide, weight 22,000 lbs.
Flywheel 30 ft. diameter, face 2 ft., weight 112,000 lbs.

A MODERN 1400-H. P. CURTIS STEAM TURBINE

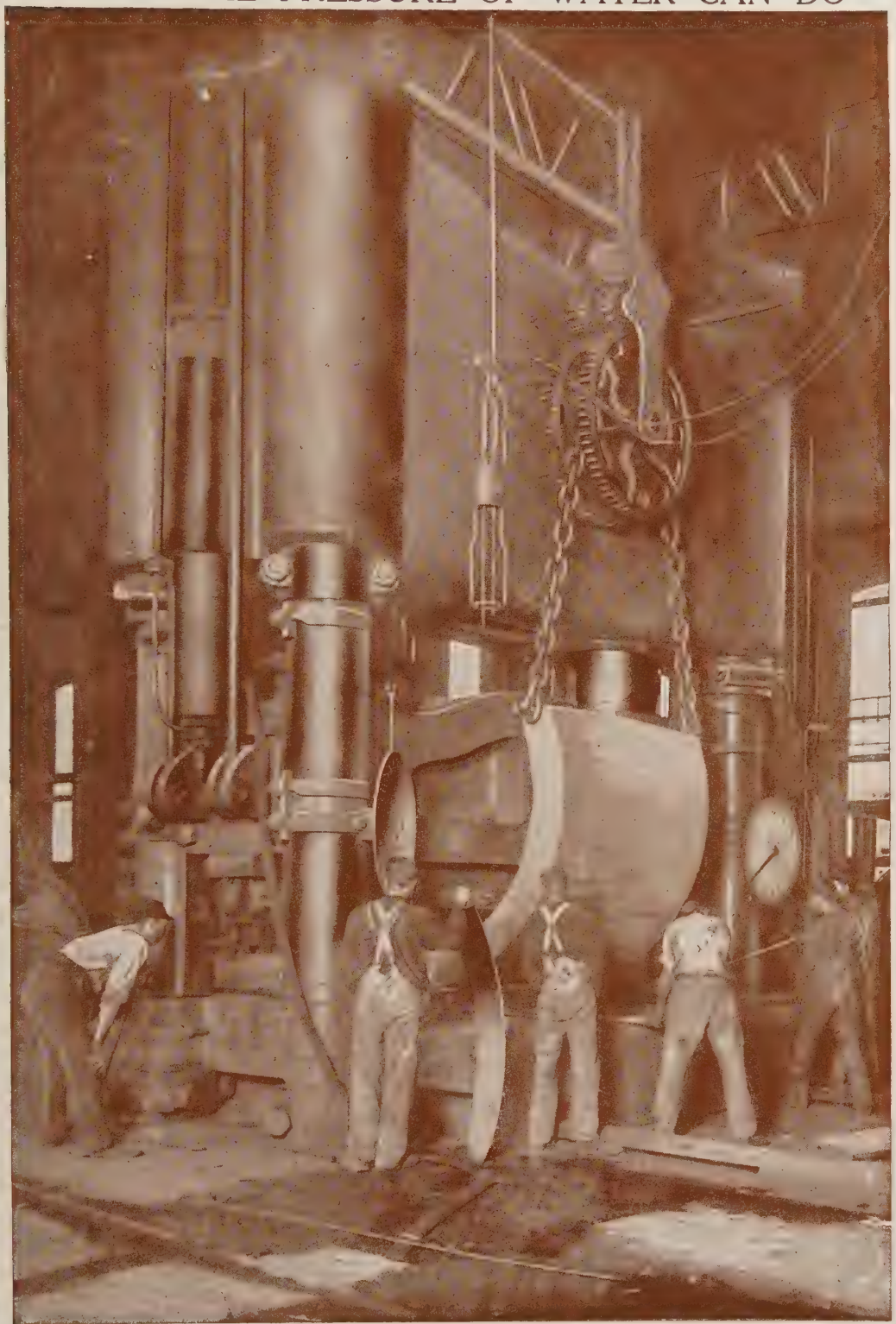
Length 17 ft.
Height 7 ft.
Steam pressure 150 lbs. per sq. in.
Speed 3600 r. p. m.
Weight 44,000 lbs.

A CONTRAST IN SIZE BUT OF EQUAL POWER

This illustration shows the difference in size between a reciprocating steam engine and a steam turbine of about the same power. In this particular plant the turbine is a low-pressure unit, using only the steam which has done its work in the reciprocating engine. The turbine will develop about 98 per cent of the power of the engine.

As the difficulties in transmitting power over long distances lessen, the possibility of great extensions in railway electrification becomes more certain. The advantages are very great and attractive, as we have seen in the suburban lines and in the subways. Consider a moment what its extension would mean: no coaling and watering of engines; trains more frequent; no smoke or steam to foul the air of tunnels; less difficulty in ascending gradients, since motors are constructed with much excess capacity. Railroad companies, too, can coöperate in the erection of power-stations in favored districts to utilize sources of cheap fuel and convert it into electricity on the spot. Though the time is not ripe for these developments, he would be a bold engineer who, in face of the wonderful growth of the last twenty years in electrified suburban traffic, would predict that main line electrification is impracticable.

WHAT THE PRESSURE OF WATER CAN DO



A BENDING-PRESS CAPABLE OF EXERTING A PRESSURE OF FOURTEEN THOUSAND TONS

FACING PAGE 1856

THE SHIPPING OF THE WORLD

The Growth and Expansion of the Chief Instrument of International Commerce

GREAT BRITAIN'S SUPREMACY ON THE SEA

THROUGH many changes, during long years past, the maritime supremacy of Great Britain has remained. The coming of oil-fuel may work to her disadvantage, because she has much native coal but no native oil. So far, however, she has kept an almost incredible degree of mastery, as iron has beaten wood, and as steam has beaten sails.

Before the Great War, $500,000,000, at least, and probably much more, were earned every year by the ocean ships of Great Britain. Her mercantile marine carried not only the greater part of her own sea-borne trade, but no small part of the trade of the entire world. Indeed, much income has been earned for Great Britain even by ships which never ply her shores, but which carry between foreign ports only.

An island race should naturally be a maritime people, and the British Isles are obviously situated in a position of advantage for sea traffic. Position, however, is not the only explanation of British sea-power. For France and Spain are just as well situated. The latter two nations have mercantile marines of considerable dimensions actually, but relatively to British sea-power their united shippings appear exceedingly small.

Added to an excellent geographical position and fine ports, Great Britain, as we have already seen, has some of the best known supplies of coal, placed by nature near to good ports. This has much to do with the later developments of British shipping. Since the industrial revolution, when Great Britain became a great importer of food and raw materials, coal exports, affording good outward cargoes, have served to balance the bulk of imports and exports from the ship owners' point of view, and to make British shipping profitable. Coal exports have enabled a large proportion of her ships to earn freights both inwards and outwards, with advantage not only to ship owners, but to the purchasers of foods and material who, if sufficient outward shipments did not exist, would have to pay in effect for the working of a ship both inwards and outwards. It is thus a very great part which coal exports have played in British mercantile progress.

Let us see how Great Britain stands in the world of shipping; and before we come to look at the available records let us remind ourselves how ships are measured. A ship is said to be of so many "tons". "Gross tonnage" is the solid contents of a vessel expressed in "tons" of 100 cubic feet. A gross ton of shipping is thus a *measurement* ton, and not a ton by weight. The "net tonnage" of a vessel is the gross tonnage, less a certain deduction made for "crew space" in the case of sailing-ships, and a further deduction for the space occupied by engines and boilers in steamships.

Both gross and net tonnage, based upon measurement rather than upon weight, are called "registered tonnage". Tonnage taxes, canal dues, etc., are levied on the basis of registered tonnage. But the rules of different governments and of the Suez and Panama canals differ with respect to the methods by which tonnage calculations shall be made.

THE GROWTH OF THE MOST IMPORTANT MERCHANT NAVIES OF THE WORLD SINCE THE YEAR 1891

(From Lloyd's Register of Shipping)

(The figures for steamships in all the years and for sailing ships in 1925 are given in gross tons; for sailing ships prior to 1925 the figures are in net tons.)

Countries	1891		1908		1925	
	Sail and Steam	Steam Only	Sail and Steam	Steam Only	Sail and Steam	Steam Only
Great Britain	10,586,000	8,168,000	17,318,000	16,367,000	19,441,000	19,305,000
British Dominions	1,343,000	485,000	1,391,000	1,163,000	2,781,000	2,603,000
Total, British Empire	11,929,000	8,653,000	18,709,000	17,530,000	22,222,000	21,908,000
Denmark	296,000	169,000	734,000	660,000	1,060,000	1,022,000
France	1,083,000	848,000	1,884,000	1,417,000	3,512,000	3,320,000
Germany	1,678,000	1,055,000	4,232,000	3,839,000	3,074,000	3,006,000
Holland	401,000	247,000	877,000	842,000	2,601,000	2,588,000
Italy	828,000	304,000	1,285,000	903,000	3,029,000	2,931,000
Japan [1]	151,000	151,000	1,140,000	1,140,000	3,920,000	3,920,000
Norway	1,665,000	305,000	1,983,000	1,352,000	2,681,000	2,618,000
Spain	539,000	423,000	701,000	677,000	1,185,000	1,143,000
Sweden	473,000	190,000	954,000	732,000	1,301,000	1,254,000
United States						
Seagoing	[2]	[2]	2,802,000	1,616,000	12,949,000	11,931,000
Lake and coasting			2,008,000	1,895,000	2,365,000	2,277,000
Total United States	1,943,000	587,000	5,910,000	3,511,000	15,414,000	14,208,000
Other Countries	1,925,000	882,000	3,660,000	3,148,000	4,774,000	4,463,000
Grand Total (all the world's ships)	22,913,000	13,816,000	40,920,000	35,723,000	64,641,000	62,380,000

[1] No sailing vessels owned by Japan are listed in Lloyd's register.
[2] Separate figures on ocean and lake vessels not registered in 1891.

For example, the steamship *Kentuckian's* registered tonnage is 6515 by British, 6582 by American, 7041 by Panama and 6659 by Suez Canal rules. There are similar differences in the net registered tonnage of the several governments and canals.

"Displacement tonnage" is a measure of weight rather than of cubic capacity. The weight of a vessel is, of course, equal to the weight of the water it displaces. Displacement tonnage, when the vessel is empty or "light" is different from displacement tonnage "loaded". "Deadweight tonnage" is the difference between displacement tonnage light and displacement tonnage loaded. It is the best measure of the maximum carrying capacity of a ship when the cargo is heavy rather than bulky, so that cubic capacity is not the limiting factor.

It is in gross tonnage that the facts in the accompanying statement are expressed, unless otherwise specified. Here we have a clear expression of the shipping progress of the world up to the year 1925. All the principal maritime nations are included in the table, and the remaining ships are negligible by comparison.

The first point to which attention should be directed is the decline of the sailing vessel. In 1880 there were nearly fifteen million tons of sailing vessels belonging to the countries named, which owned nearly all the ships of the world. In 1891 they had declined to about two-thirds of that, or say ten million tons.

The progress of the steamship has been even more remarkable than the decline of the sailing vessel. In 1880, there were less than six million tons in the world; in 1891, there were over thirteen million tons; in 1908, there were over thirty-five million tons. It was in the early 'eighties of the nineteenth century that the construction of steamships took the lead; and when we remember that a steam-ton is the effective equivalent of three sailing-tons, we see how enormous must have been the development of commerce in the last generation. When we say that in thirty years the world's steam tonnage increased by about 20,000,000 tons, this means that it increased by the equivalent of 60,000,000 tons of sailing ships. As, in the same time, the decline of sailing ships was 6,000,000 tons, we get the result that, expressed in the equivalent of sailing-tons, *the world's ships grew by about 54,000,000 sailing-tons in only thirty years.*

And with all this progress Great Britain held an astonishing supremacy. Whereas in 1880 she had about six and a half million tons of shipping, in 1908 she possessed more than seventeen million tons. This is to lump steam and sailing ships together, but we get a truer idea of British maritime advance if we consider steam tonnage alone, as has been done in compiling the following figures:

THE WORLD'S STEAM TONNAGE

	1891	1908	1925
Great Britain .	8,700,000	17,500,000	21,900,000
Rest of the world	14,200,000	18,200,000	42,700,000
All the world . (except a few unimportant items)	22,900,000	35,700,000	64,600,000

We see that, in 1908, out of 35,700,000 steam-tons possessed by nearly all the world, Great Britain owned as many as 17,500,000 tons. And even this is an understatement of Britain's real position. It will be readily understood that there are tons and tons, even among steam vessels. The best and the fastest vessels of the world were chiefly owned by British ship owners, so that in tons effective Great Britain possessed a larger proportion even than is shown in the above figures, good as they seem without further examination..

There is another consideration of importance in this connection. It is that the above record includes all the ships of the United States. The greater part of these, however, were vessels which ply only in the lake and coasting trades of America. If we rule out these, America had a very small mercantile marine engaged in ocean traffic. The United States possessed about 1,600,000 steam-tons, and less than three million steam- and sailing-tons, engaged in ocean commerce. If we include these only to obtain proper comparison, we get the following record of the leading maritime powers in 1908:

THE LEADING MARITIME POWERS

(Steam-Tons Only)

Country	1908	1925
Great Britain	16,337,000	19,305,000
Germany	3,839,000	3,006,000
United States . . . . (ocean ships only)	1,616,000	11,931,000
France	1,417,000	3,320,000
Norway	1,352,000	2,618,000
Japan	1,140,000	3,920,000
Italy	903,000	2,931,000
All Other Nations . .	9,119,095	15,349,000
Grand Total	35,723,095	62,380,000

There were only eight nations in the world which possessed over half a million tons each of ocean steam shipping, and these were, in the order of their importance, Great Britain, Germany, the United States, France, Norway, Japan, Italy and Spain. All the rest of the world put together possessed only about nine million steam-tons, making, with the eight countries named, less than thirty-six million tons. Of these nearly one-half were the property of British ship owners, which means that in effective tonnage Great Britain possessed *much more than one-half* of the steamships of all the world.

Germany a poor second in respect to maritime supremacy

Germany was second in the race, but she was a poor second in this respect to Britain, as will be seen. Nevertheless, we have to remember that she has a very poor seaboard, and nothing like the natural advantages for shipping which are possessed by, say, France or Spain. Her position, indeed, as compared with other countries, and especially as compared with the United States, was exceedingly creditable. Germany had fostered her shipping with great solicitude; and the fact that she ranked next to Great Britain is another proof of her commercial genius and of the determination with which she faced even inherent disadvantages.

The wonderful rise of Japanese shipping is especially noteworthy. As recently as 1880, Japan possessed a mere forty thousand tons of steamships; in twenty-eight years this paltry figure had been swollen to 1,140,000 tons, raising Japan to the position of the sixth maritime nation in the world. It was a sensational advance. It was sea-power which gave Japan the advantage in the Russo-Japanese War, illustrating once more for how much sea-power counts in the world and in the making of the history of nations.

How imports and exports are the same goods

How important these considerations are will have been gathered from preceding chapters. The services of Great Britain's ships were in very truth "exports" which earned imports for her just as truly as though she had sent out goods. Either by estimating the earnings of ships on the basis of tonnage, or by a deduction from the total value of the world's commerce, we can arrive at an approximate idea of what ships earn in the course of a year. The latter method is an exceedingly simple one. If we take the imports and exports of all the principal countries of the world, we find that the imports exceed the exports in value. Why is this? Obviously, the imports and exports are the *same goods*, entered as "exports" by the countries which send them out, and as "imports" by the countries which bring them in. The explanation is that, as a general rule, goods exported are valued by custom houses at their price as sold, and before they are increased in value by transport to their destination in the importing country. On the other hand, when the goods arrive at their destinations as "imports," they are valued at the customs with the addition of the cost of their transport (c. i. f., or cost, plus insurance, plus freight).

Why the imports of all countries add up greater than the exports of all countries

Thus if a locomotive costing $25,000 is exported from London to Buenos Aires, and the freight and insurance charges come to $2500, then in the British trade returns there appears an "export" of $25,000 worth, and in the Argentine trade returns, there appears an "import" worth $27,500. That is why the imports of all countries, added together, come out at a bigger figure than the exports although they relate to the same goods.

If we aggregate the pre-war imports and exports of most of the countries of the world, we find that the imports reach $16,600,000,000, while the exports total $15,300,000,000. So the imports exceed the exports thus:

Imports	$16,600,000,000
Exports	15,300,000,000
Imports exceed exports by . .	$ 1,300,000,000

Approximately, therefore, the transportation of the goods concerned — as we may say, the transmutation of "exports" into "imports" — cost $1,300,000,000. This sum, roughly, was earned by all the world's ocean-going ships. But, as we have seen in this chapter, Great Britain owned about one-half of all the world's ocean-going ships. Therefore we deduce the estimate that British ships earned approximately $650,000,000 in a year. Of course, it is not possible to estimate the figure with exactitude. It is perfectly clear, however, that Britain's mercantile marine is among its most valuable commercial and industrial assets.

The number of persons employed in the mercantile marine accounts for but a small proportion of Great Britain's population. The facts of the case are that all the ships belonging to Great Britain, excluding only vessels employed on rivers and canals, whether employed in the coasting or foreign trades, and including fishing-vessels, found employment for about 200,000 British seamen, 35,000 foreign seamen, and 45,000 Lascars and Asiatics, many of whom were British subjects. These figures include the masters and other officers of vessels. And, owing to the increase in steamships, the number of men employed did not grow with the growth of shipping. So an enormous increase in shipping has been worked, through the progress of navigation, by a slightly increased number of men. The possession by Britain of such a great carrying trade is a natural stimulus to the shipbuilding industry. British shipyards find in British ship owners a magnificent home market, and they are able, in addition, to command valuable markets abroad. Great Britain's primacy in ship-building is even more remarkable than in ship-owning. When one first becomes acquainted with the nature of the case, one is inclined to doubt the facts, so extraordinary do they appear.

In 1911 British shipyards built over 2,000,000 tons of shipping, that is this tiny island country turned out *two-thirds of all the ships built in the world.*

The deeply interesting ship-building record of the first twenty years of the century is given in the accompanying table, and for many reasons it will repay careful examination. We have stated figures for all the world, Great Britain, Germany, the United States and France, respectively. The first thing to observe is that, in each of the twenty years shown, British shipyards constructed most of the ships built, and usually something like two-thirds of the whole. Most of the ships that pass through the Suez Canal fly the British flag. From the annexed statement something more than that will be realized, and it is that a large proportion of the vessels which did not fly the British flag were constructed in British shipyards. We get a picture of British shipyard workers constructing the vessels that carried the greater part of the wonderful trade of the world.

NUMBER AND TONNAGE OF MERCHANT VESSELS OF ONE HUNDRED GROSS TONS AND UPWARDS, LAUNCHED 1905–1924

Year	United Kingdom		France		Germany		United States		The World	
1905	795	1,623,168	43	73,124	148	255,423	200	302,827	1,576	2,514,922
1906	886	1,828,343	48	35,214	205	318,230	242	441,087	1,836	2,919,763
1907	841	1,607,890	50	61,635	188	275,003	255	474,675	1,788	2,778,088
1908	523	929,669	50	83,429	120	207,777	238	304,543	1,405	1,833,286
1909	526	991,066	51	42,197	84	128,696	102	209,604	1,063	1,602,057
1910	500	1,143,169	55	80,751	117	159,303	195	331,318	1,277	1,957,853
1911	772	1,803,844	79	125,472	154	255,532	142	171,569	1,599	2,650,140
1912	712	1,738,514	80	110,734	165	375,317	174	284,223	1,719	2,901,769
1913	688	1,932,153	89	176,095	162	465,226	205	276,448	1,750	3,332,882
1914	656	1,683,553	33	114,052	89	[2] 387,192	94	200,762	1,319	[2] 2,852,752
1915	327	650,919	6	25,402	[1]	[1]	84	177,460	743	[2] 1,201,638
1916	306	608,235	9	42,752	[1]	[1]	211	504,247	964	[2] 1,688,080
1917	286	1,162,896	6	18,828	[1]	[1]	326	997,919	1,112	[2] 2,937,786
1918	301	1,348,120	3	13,715	[1]	[1]	929	3,033,030	1,866	[2] 5,447,444
1919	612	1,620,442	34	32,633	[1]	[1]	1,051	4,075,385	2,483	[2] 7,144,549
1920	618	2,055,624	50	93,449	[1]	[1]	509	2,476,253	1,759	[2] 5,861,666
1921	426	1,538,052	65	210,663	242	509,064	173	1,006,413	1,377	4,341,679
1922	235	1,031,081	62	184,509	195	525,829	59	119,138	852	2,467,084
1923	222	645,651	27	96,644	117	345,062	83	172,817	701	1,643,181
1924	494	1,439,885	26	79,685	108	175,113	79	140,063	924	2,247,751

[1] No returns.

[2] Returns not complete.

Variability and fluctuation of trade indicated by the record of ship-building

It is not necessary to dwell upon the figures for Germany, America and France, which were insignificant by comparison with England's. It is more important to direct attention to another vitally important consideration which is brought home to our minds by this record of ship-building. It is the variability and fluctuation of trade to which it points. Whether we look at the British, the German, the American or the French figures, or whether we take the figures of the whole world, we see wide fluctuation from year to year, and sometimes fluctuation of a most extraordinary character in the space of a short twelve months.

The decline in employment in a single year

Look, for example, at the years 1907, 1908 and 1909. In 1907, 2,778,000 tons of ships were built in all the world; next year the tonnage built in all the world fell to 1,833,000 tons; and in the year following there was a further fall to 1,602,000 tons. This, of course, was the result of the wave of depression that swept over the whole world of commerce in 1908–9; there was a "slump", to use a familiar term. We get these slumps pictured in the ship-building industry in an exaggerated form, for the simple reason that the industry is engaged in making an instrument of commerce, and that it feels, as it were, a concentration of the depressions of all other trades. If we consider what this means to the men who construct ships, we have something to give us pause. In 1907, about 2,800,000 tons were constructed; in 1908, about 1,800,000 tons; that means a decline in employment in all the world's shipyards, in a single year, in the ratio of 100 to 64 (about). That means, of course, that where in 1907 there was work for 100 shipyard workers, in 1908 there was work for only 64. That means no work in 1908 for one out of three of the men who were at work in 1907; and in the following year the number fell again. After that came revival, and in 1911 complete revival.

Such are the facts we have to face in industry and commerce at the beginning of the second decade of the twentieth century. Such are the disharmonies and imperfections which still bring sorrow and poverty and distress to millions of industrial workers throughout the world every few years.

British ship-builders' proud position

In addition to building 1,399,770 tons for the British merchant marine, and 221,430 tons of British warships, British shipyards, in 1911, constructed 404,074 tons for foreign merchant marines and 9356 tons of war vessels for foreign governments. Among her biggest customers, Norway, the British dominions, Austria-Hungary, Holland, Germany, South America and Sweden were prominent. Altogether, it is a proud position which is held by British ship-builders.

The distribution of the ship-building industry in Great Britain presents some points of interest. For the most part it is carried on near coal mines, and especially where good ports are near coal mines. Most important of the ship-building centers are, in order, Newcastle, Glasgow, Sunderland, Greenock and Belfast. London does not appear in this list; that is because of the marked effect of situation upon the economics of wealth production. Although London is a great port, and ship-repairing must necessarily be done there, ship-builders on the Thames cannot compete for economic reasons with the northern shipyards, or at least they appear to have the greatest difficulty in doing so, whether in regard to ships for the mercantile marine or ships for the British navy.

Distress where building is concentrated

Where there is considerable concentration of ship-building at one port, as at Glasgow, Greenock, Newcastle or Sunderland, the distress from the fluctuations, which we have already seen to be an especial accompaniment of the industry, is very severely felt, owing to the large proportion of shipyard workers among the populations of the towns.

Canada's and Australia's splendid showing in steamship tonnage

The British Empire outside Great Britain, owned before the Great War about 1,500,000 tons of steamships, chiefly possessed by Canada and Australia. In the time to come we may expect to see these figures very largely increased, for Canada and other British dominions are well situated for commerce, and have excellent seaboards and fine ports. Canada, in fact, had in 1921 a merchant marine of almost 2,000,000 gross tons, not much more than half of which was made up of sailing vessels. This is not far short of the figures reached by such countries as Spain and Sweden.

Early history of the U. S. merchant marine very different from that of England

The history of the merchant marine of the United States has been very different from that of England. A promising beginning, a rapid and even spectacular growth, and an even more sudden collapse are its outstanding features. With the shipping revolution, brought about by the recent war, a new and promising beginning has again been made. The present position and the future possibilities of American shipping will be discussed in a subsequent chapter. Our present task is to review the earlier maritime experience of the United States and to try to discover the causes of the meteoric rise and fall of its shipping.

Ship-building came to be an important industry in America in the Colonial period. The British Navigation Acts, which have sometimes been held to restrict the colonies because they prevented them from shipping their goods in other than British vessels, were really of great advantage to them, for vessels built in the colonies were considered British vessels and were in all respects on the same footing as those built in England. Ship timber of the finest quality was close at hand to the ports — a matter of much importance when it was difficult and even impossible to haul heavy timbers overland. So great, in fact, were these advantages that the colonists not only built ships for themselves, but sold ships to Great Britain. Perhaps a third of the British tonnage just before the Revolution had been built in America.

How the Yankee skippers adventured into new and distant trade routes

Sailing their ships as well as building them, the American colonists carried a large part of their own ocean traffic, and this remained true after the Revolution. The exclusive commercial policies of European nations, which made it difficult for American ships to engage in commerce with them or with their colonies, merely led the enterprising Yankee merchants and skippers to adventure into new and distant trade routes. The West and East Indies, the west coasts of North and South America, the Pacific islands, China, the east and west coasts of Africa, the Mediterranean ports, were visited by American ships in a successful search for new and profitable trade routes. A letter of instruction of 1792, written by a Salem merchant and ship owner to Captain Ward of the brig *Enterprise* is quoted in Professor S. E. Morison's "Maritime History of Massachusetts": "He will dispose of his Russia duck, 'coles' (from Liverpool), and anything that he may think proper, at the Cape of Good Hope. There he is to pick up wine, brandy, raisins, and almonds for the Île de France, where the whole cargo ought to sell for one hundred per cent profit, provided the *Enterprise* arrives before a certain Boston vessel. Captain Ward is to purchase there anything that will pay cent per cent at Salem, according to a list of prices current furnished him. His next stop should be Calcutta to take on sugar, saltpeter, and 'Bandanno silk Handkerchiefs' at the same rate. Otherwise he must try to get a 'cheep' cargo of teak to exchange at Canton for China goods. He may even sell the brig, if a good opportunity offers. As the Captain did not find prices low enough for his owner's modest expectations, he took freight from India to Ostend, and there filled his hold with European merchandise."

The effect of the Napoleonic wars on American commerce and shipping

The Napoleonic wars in Europe led not only to a great increase in American commerce, but to an enormous increase in American merchant shipping. The ships of other countries were fair prizes to their enemies. The United States was the only country in the world in a position to engage in "neutral trade" on a large scale. In 1790 the tonnage of American ships was hardly more than 100,000; by 1810, it had increased nearly tenfold. Finally, however, in their desperate efforts for victory, both Napoleon and the English government restricted neutral trade so far that the United States retaliated in 1807 with an embargo, forbidding its vessels to leave for foreign ports. The War of 1812 soon followed with further injury to American shipping interests.

It was not till after that war, with the war in Europe also ended and shipping again subjected to foreign competition, that the American merchant marine entered upon the period of its greatest prosperity. The commerce of the world was still carried in wooden sailing ships. By reason of the availability of raw materials and of acquired skill in construction, the United States was able to build such ships more cheaply and more efficiently than any other country. The energies of its ablest merchants were thrown into the development of maritime trade, the most enterprising of its young men were likely to be drawn to serve an apprenticeship at least in a seafaring life. In 1855 its mercantile marine was larger than it had ever been before, or than it was ever again up to the recent war. At the time of the Civil War, American ships constituted one-third of the world's tonnage. The British Empire had about as large a share, while all other countries taken together had no more than either the United States or the British Empire.

The causes of the decline of American shipping were various and complicated. In the first place, the Civil War was responsible for the loss of no less than one million tons of shipping. No less than two hundred and sixty vessels were destroyed or captured at sea by Confederate cruisers. Northern ship owners found it profitable to sell their ships to foreigners who could navigate them more safely and at lower insurance rates.

In the second place, the maritime supremacy of the United States had been founded upon the wooden sailing ship. American designers and builders shortly before the Civil War had carried the sailing vessel in the form of the clipper ship to the highest point of perfection in respect to beauty, speed and general efficiency that it has ever reached. Now, however, steam power had begun to supplant the sailing ship, just as iron and later steel supplanted wood as the material of construction. For various reasons, it cost more to build and sail ships in America than in England.

Capital and energies of the United States absorbed in internal developments

In the third place, and undoubtedly most important of all, the energies of the people of the United States were turned in other directions. The development of the Middle West and later of the Far West, the construction of the world's most extensive railway system, the rapid rise of manufacturing industries — these and similar matters absorbed the capital and the energies of the United States to a large extent.

The building and operation of ships, like other economic activities, is subject to the law of comparative costs. It was not merely a question of whether the United States could build and operate ships at the cost in money outlay as low as English ship owners would have to make; it was in larger measure a question of whether by building and operating ships, the United States could reap such returns as from other alternative domestic employments of labor and capital. What ship-building on a larger scale would have cost cannot be measured merely in terms of money outlays; the really significant costs have to be measured in terms of the alternative industrial opportunities that would have been passed over.

Contrasting conditions at the beginning and end of the nineteenth century

At the beginning of the nineteenth century, the United States was carrying no small part of the trade of the world. At the end of that century, it was carrying less than one-fifth of *its own* trade. Whether or not this decline should be deemed humiliating depends upon the point of view. It is clear, however, that the decline must be attributed in large part to the fact that under new conditions, the United States found it more profitable to employ the ships of other nations to do its carrying for it and to repay them in goods in the production of which it had a greater comparative advantage than in building and operating ships.

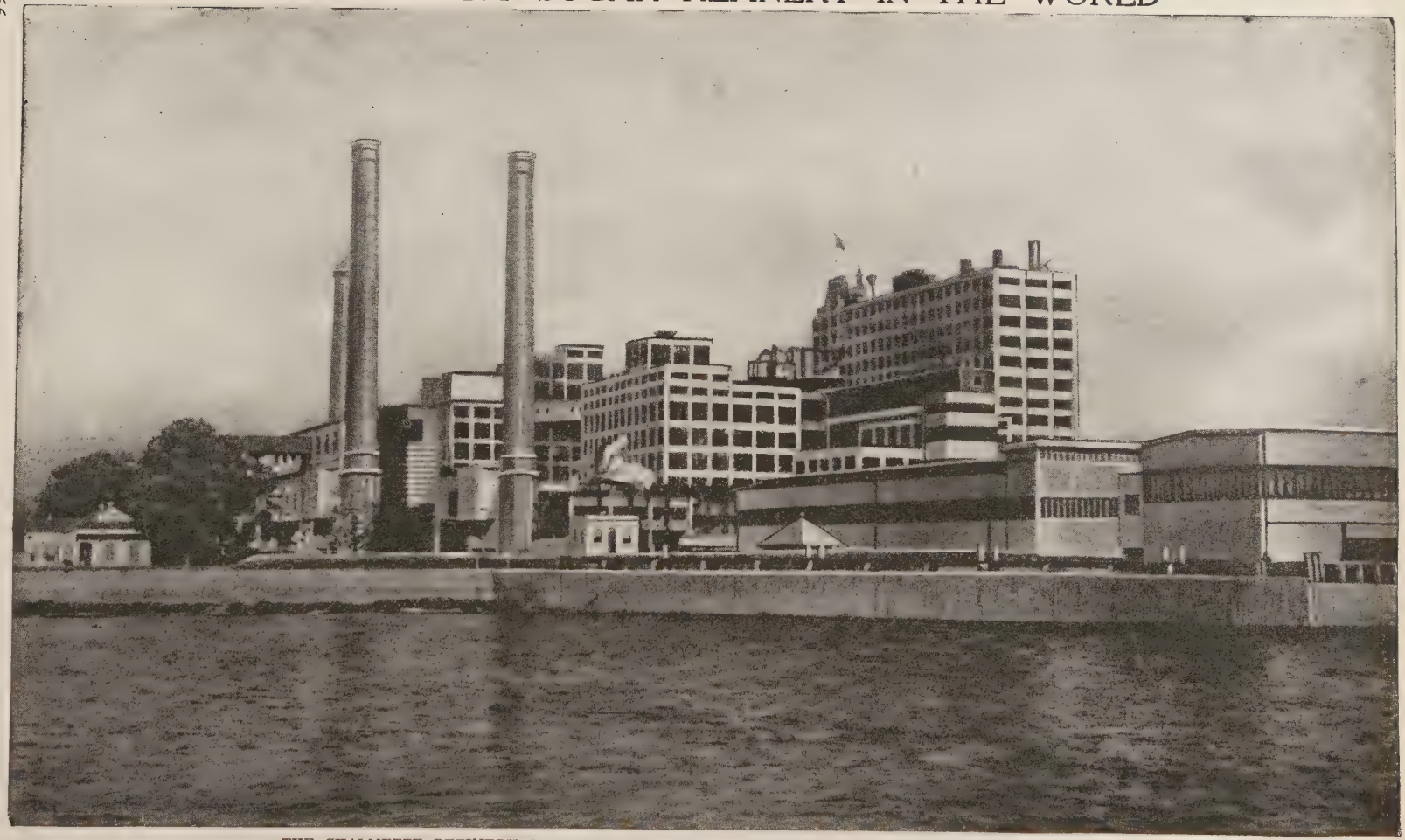
Finally, it is to be observed that England's free trade policy has had much to do with the maintenance of her maritime supremacy. In fact, it is likely that England's coal exports and her free trade policy have had more to do with the success of her shipping industries than any special advantages she may have had in building and operating ships. More than a hundred years ago, the Yankee skippers found that regular and dependable cargoes could not be got by handling merely their own export and import trade, or that of any other one country. Where trade is regular and dependable, competition becomes intense, and shipping profits become relatively small. But the trade of any one country is rarely regular and dependable. It is subject to seasonal variations, to fluctuations resulting from changes in price levels, from crop failures, and the like. The really serious problem is that of getting return cargoes. Where traffic is in one direction only, shipping costs are doubled. Now a vessel from whatever part of the world going to an English port could be sure at least of getting coal as a return cargo; and it is more profitable to carry coal, even at a low rate, than to carry ballast. It is a fact of enormous significance that before the war two-thirds of England's exports in tonnage (not in value) were coal!

In addition, a vessel going to a British port was not limited to carrying goods destined for British markets. Without payment of customs duties, or the slightest formality of any sort, goods from any part of the world could be brought to British ports, and there re-shipped to other foreign markets. Germany has often been complimented on her foresight in maintaining free ports at Hamburg, Bremerhaven, Geestemunde and Cuxshaven. A free port, it should be explained, is nothing but an area created by withdrawing the customs frontier at which tariff duties are collected a little way inland from the geographical or political frontier. Undoubtedly German free ports — distributing centers for much of the trade for northern Europe — had much to do with the rapid growth of German shipping before the war. But we should not forget that for the better part of a century every port in the United Kingdom has been a free port, nor that this fact has had much to do with the development of Britain's enormous entrepôt trade, nor that that trade in turn has had much to do with the success of British shipping.

EVOLUTION OF THE ATLANTIC LINER

Date	Name	Gross Tonnage	Length (Feet)	Horse-Power	Speed Knots (per Hour)	Material
1833	Royal William	.....	176	180	.....	Wood
1838	Sirius	700	208	320	7.5	"
1838	Great Western	1,340	236	440	9	"
1840	Britannia	1,156	207	740	8.5	"
1843	Great Britain	3,270	302½	1,000	.....	Iron
1848	America	1,825	251	1,400	10.25	Wood
1850	Baltic	3,000	282	800	.....	"
1850	Asia	2,226	266	2,400	12.5	"
1855	Persia	3,300	376	3,600	13.8	Iron
1858	Great Eastern	18,914	680	6,600	13.5	"
1865	Java	2,697	337	2,650	14	"
1867	Russia	2,959	358	3,100	14.4	"
1871	Oceanic	3,808	420	3,000	14.75	"
1874	Britannic	5,004	455	5,500	16	"
1875	City of Berlin	5,490	488½	4,799	16	"
1881	Servia	7.391	515	9,900	16.7	"
1884	Umbria	8,127	500	14,500	19.5	"
1888	City of Paris	10,669	527½	18,000	19	"
1888	Teutonic	9,984	565¾	16,000	21	"
1893	Campania	12,500	600	26,000	22	"
1901	Kaiser Wilhelm II	19,361	678	45,000	23.5	"
1901	Celtic	20,904	680¾	.....	.....	"
1907	Mauretania	31,938	762	70,000	25	"
1910	Olympic	46,000	882½	50,000	22	"
1913	Imperator	52,000	911	61,000	22	"
1914	Aquitania	47,000	901	60,000	23	"
1914	Leviathan	54,282	907½	.....	25	"
1921	Majestic	56,551	915	66,000	25	"

THE LARGEST SUGAR REFINERY IN THE WORLD



THE CHALMETTE REFINERY OF THE AMERICAN SUGAR REFINING CO., NEW ORLEANS, LOUISIANA
Production 3½ million pounds per day.

THE SUGAR INDUSTRY

How the World Gratifies the
Craving of its Sweet Tooth

HOW CANE AND BEET ARE GROWN AND TREATED

SUGAR is a constituent of many plants and seeds and there are many sugars. One associates sweetness with sugar, but not all sugars are distinctly sweet. The chemist groups sugars — of which more than thirty have been isolated — under the name "saccharides" and they are perhaps more popularly known as "carbohydrates", as they are all compounds of carbon, hydrogen and oxygen. Many of them are very rare, and in a pure state are used in bacteriological investigations. The Great War forced us to produce the rare sugars that we formerly obtained in Europe, and the government laboratories in Washington were very active and successful in devising methods for their manufacture. Several of them, when perfectly pure, are sold at prices ranging up to nearly three hundred dollars a pound. Fortunately it is not these sugars that gratify the craving of the world's sweet tooth, but the familiar one that we find at the grocer's. This one is not only a very valuable food product, but is usually cheap and abundant. In a pure state it is known to the chemists as "sucrose" or "saccharose". Whether it be obtained from the beet, sugar cane, the sap of maple and other trees, sorghum, corn and other plants, or from seeds (coffee, for example), in a pure state it is sucrose and no chemical or physical test has yet been devised that can prove otherwise. Many believe that the sugar of the cane and that of the beet give different results in preserving fruits and making jellies, but no chemist has yet been able to show that the equally well refined products from the two sources differ in any respect.

The cane sugar industry is of very ancient origin, while that of the beet is comparatively recent, dating only from Napoleon's time. Sugar cane was long centered in small estates, owned by individuals, many of whom maintained beautiful plantation homes and were surrounded by every luxury that a marvelously profitable industry could supply. Often the planter had a palatial city residence and paid but infrequent visits at the plantation, leaving a manager to look after the property. So long as the manager turned over to the owner what the latter considered a fair income, there were very few questions asked, and usually both grew rich. The planters entertained lavishly on their estates and had few cares until increasing beet sugar production brought an end to the days of high prices and easy profits.

The beet sugar industry really began in 1806 with Napoleon's famous edict blockading the continent of Europe against England, although sugar had been isolated from the beet about 1747 by Margraff, in Germany, and Achard, also a German, had begun manufacturing experiments as early as 1796 and had built a factory in 1800. Under Napoleon's patronage it was prosperous, but with his overthrow tropical competition became so severe that it was only saved by bounties and tariff protection. The beet has never had the romantic surroundings that family ownership and an almost feudal system once gave the cane.

Disaster apparently faced the sugar industry in 1884–85. Production had attained such proportions that the consumption of a world not yet accustomed

to plenty of sugar could not keep pace with it. Prices fell to an unprecedentedly low point all over the world. At this time Europe was stimulating the beet with bounties and the cane was rapidly falling behind. The depression continued until about 1900 and was aggravated by the financial conditions of the last decade of the century. The industry was prosperous after the Spanish-American War and profited by the great increase in consumption. Reciprocity with Cuba, and the admission free of duty of Hawaiian, Porto Rican and a large amount of Philippine sugar, stimulated cane culture in these islands. Cane factories combined and formed large central plants, operating very largely upon purchased raw material, and small factories were dismantled. The beet soon began to fall behind the cane in production.

Overproduction was again leading to a crisis, when the Great War changed all conditions. Raw sugar was selling free on board ship in the tropics in 1914 as low as one and three-quarters cents per pound, or in most instances at below the cost of production. Many establishments had about reached the limit of their resources and a general crash was imminent. Suddenly the war broke out and there was a shortage of sugar. There was a mad rush to develop new plantings and build and enlarge factories. Labor was paid fabulous prices. Raw sugar finally reached about twenty-five cents per pound at the shipping ports, and the warehouses were gorged with it. Speculation was rampant. Finally the world awakened in 1920–21 to the fact that there was plenty of sugar for all. Sugar came out of its hiding places and was a glut on the market. More than half a crop of raw sugar was in storage in Cuba when the grinding of the new crop began. Prices had fallen to almost the pre-war level. This was the condition when the crop of 1921–22 was ready for the harvest. Many banks failed, but the world's needs, largely due to Europe's small production and the low prices, had nearly cleared the warehouses of old and new sugars and normal conditions were apparently in sight.

The cane and beet were neck and neck in the race of production in 1908, but in 1913 the total of cane sugar was nearly ten million tons against a little more than nine million of beet, while in 1921 there were eleven and a half million tons of the former produced against about five of the latter.

Cane is known to have been grown in India — its home — earlier than 300 B.C. It spread from there to all parts of the tropics, and to some sub-tropical localities, notably Louisiana and the Argentine. Sugar cane is a giant grass, genus *Saccharum*. The stalk is made up of nodes and internodes or joints. At each node there is an eye or embryo cane. It is this eye that is used in planting the fields. The stalk has a very hard rind that offers much resistance in the milling process. The stalk bears a tuft of leaves at the top and, usually when ripening, a beautiful gray plume of flowers (see accompanying illustration). The top joints are immature, containing little sugar and many impurities, and are therefore removed in harvesting. The stalks are often two inches or more in diameter near the base and frequently reach a height exceeding twenty feet. The juice of the cane is very tractable to simple methods of manufacture. Lime is usually the only chemical employed in raw sugar manufacture and this was true more than 1200 years ago. Simple methods are so easily applied that probably a very large production of sugar escapes the statistician.

In the Hawaiian Islands, except Hawaii, Java, India, largely in Porto Rico, and in many other islands, cane is grown with irrigation. Cuba, the world's largest producer, uses no irrigation in her fields, depending upon natural rainfall. Java is the second largest producer and grows all of it with irrigation.

The expansion of the sugar industry in Java is very much restricted by the government. The island is but little larger than Cuba, is well watered and has an abundance of land well suited to cane. The problem of feeding its population of about thirty-eight millions enters, and forces the government to restrict cane planting in favor of rice and other foods.

Labor is so abundant and cheap that all field operations and many of the factory, for which machinery would be used elsewhere, are performed by manual labor. The trenches in which the cane is planted are dug with pick and shovel. The tropical soil is so hard that it must be wet down before digging begins. The water for this purpose is carried in baskets or cans, often by women. Long use of the lands for rice culture, possibly for centuries, has gradually brought the area within the dikes to an almost perfect level. The fields

CUTTING DOWN THE SUGAR CANE ON A JAMAICA PLANTATION

are laid off in shallow canals at intervals of about thirty feet, and crossing these, parallel with the cane rows, are the main canals about three feet deep. In conducting the irrigation, women stand in the shallow canals, take up the water in closely woven baskets and throw it through the rows. The government or community owns the land and controls the water. The factory may only lease the former for a single crop of cane and then must return it in suitable condition for other food crops, but government control always assures the factory sufficient land. The land tenure limits Java to a single cutting of the cane, that is, to the "plant" or the first cutting after planting. The cane is literally dug out of the ground with mattocks, so as to free the land of the stubble and conserve the underground portion of the stalk. In most other countries, the cane is cut close to the ground with flat-bladed knives and the stubble is left to sprout and produce another crop of cane, and so on for several years. It is said that cane would not produce well from the stubble in Java. The agriculture of Java is typical of the skill and intensive methods of the Dutch in their home fields and the yields of cane and sugar are correspondingly large. Notwithstanding the extensive use of manual labor in preparing the soil and the government's limitation to one crop of cane on the land in each three or four years, Java produces sugar more cheaply than her competitors, whether beet or cane.

Irrigation is practised in British India much as in Java. In the Hawaiian Islands all agriculture has been brought to an in-

tensive state and the yields of cane and sugar are unsurpassed. Probably nowhere else are there such extensive irrigation systems, except under government ownership. Extensive pumping plants are maintained, and irrigation is a very large element of cost.

With the exception of two or three plantations, Cuba depends only upon natural rainfall. The year is divided into a wet and dry season, though some rain falls each month. The rainy season prevails during the hot months from May to November, or at the time the cane most needs heat and moisture. The cane ripens in the cool dry weather of November and December and is ready for sugar-making about the beginning of January. The price of sugar, however, usually determines the start of sugar-making. If the price is high, cane grinding may begin early in December, but with low yields of sugar from the immature cane. In a part of the northeastern coast, there is a section where there are really two dry seasons. Here grinding begins in January and continues normally until in May, when it is more or less interrupted by rains until July, when fairly dry weather prevails until September or even later. It is here that the world's greatest factories and plantations are located. In Peru and in parts of the Hawaiian Islands it is also possible to make sugar during an even longer period than in northeastern Cuba, since irrigation is the sole dependence for moisture.

Cane is planted from cuttings, though it produces fertile seed. Plants from the seed, however, do not reproduce the characteristics of the parent stalks. The procedure in planting varies with the moisture conditions and the land. With irrigation cane may be planted at any time, but without it only after copious rains. The stalks of seed-cane are cut into pieces or "seed", each including two or three "eyes" or embryos at the nodes. The top joints of the cane, that are discarded by the factory, are used for seed where irrigation is practised and produce superior cane to that from eyes lower on the stalk. The seed is distributed at close intervals, single file, in a furrow and then lightly covered with soil.

Methods of planting vary in different countries and with soil conditions, but this is the customary one in most tropical regions. The plantlets appear after a few days. The soil is gradually worked up to them as they grow and the weeds kept down. Soon the cane is large enough to shade the rows and cultivation then ceases. Under usual conditions, with plenty of moisture and sunshine, the cane is ready for harvesting in about nine months, though it is usually allowed to grow for fourteen to eighteen months and often longer. In most countries it is customary to plant at two periods, after the spring and the fall rains. The resulting cane is designated as "spring plant" and "fall plant". New canes spring up from the stubble left in harvesting and are termed "stubble" or "ratoons". Java produces only plant cane in order to free the land for other crops in rotation. Cane will ratoon profitably many times on good strong land, though usually three to five harvests are gathered from a single planting.

The Cuban method of clearing forest land and planting in virgin soil is followed in all Spanish America. The trees are felled and the jungle cut down and left to dry. The falling trees are so directed as not to obstruct the carts, the wheels of which are so large that the axles clear the stumps. Valuable timber, such as Spanish cedar, mahogany and other hard woods, is usually drawn from the fields, though during the Great War vast quantities were destroyed in the haste to obtain new fields. Finally, when weather conditions are favorable, the brush is fired and soon the new field is a wilderness of stumps and blackened trunks. The land receives no further preparation for the cane. After a few heavy rains have fallen, thoroughly soaking the ground, planting begins. A hole is made by thrusting a bar into the ground and a short piece of cane is placed in this and the soil pressed closely about it. This operation is repeated at frequent intervals and in rows about six feet apart. The only cultivation this cane receives is an occasional hoeing. These rich virgin soils produce many crops of cane before replanting is necessary.

The cane is subject to many diseases, insect pests and mammals (rats). Certain borers and other insects are combated by their own enemy parasites. The world has been ransacked in the search for suitable parasites. An extremely interesting fight to preserve an industry against disease was that of Java. A disease known as "sereh", and not positively identified except in Java, began to spread rapidly over the island and about 1882 was considered a very serious menace to the cane.

Java began experiments with the true seed of the cane in 1888 and developed several new varieties that have played an important part in her cane fields. Millions of seedlings were grown and tested. From these, perhaps, a dozen commercially valuable varieties have been selected and several have practically superseded the old varieties. Through the intensive study of the canes and the introduction of new seedling varieties, the Java industry was saved and became stronger than ever.

Photo Ewing Galloway, N. Y.

SUGAR CANE PILED UP AT A LOUISIANA MILL

Intensive studies of the sereh led to the conclusion that it is hereditary and that healthy canes are not attacked in the first generation or two. It was also found that canes grown at high altitudes were healthy and immune to the disease in their own habitat. This led to the establishment of seed nurseries in the mountain valleys and seed-cane was grown there for planting in the low lands. Though the fertility of the cane had been observed in 1859, this was not rediscovered until 1888-89, and not in time to be of any help to Java's sugar industry.

Experiment stations are at work in many parts of the tropics growing and selecting seedlings. Literally millions of plants have been grown and all but a very few have been rejected. Cane from seed is extremely subject to variations, and the seedlings have very little tendency to inherit the qualities of the parents. The methods used to improve the sugar beet cannot be followed. The study is one of intense interest, and further experimental work will undoubtedly ultimately result in canes that will very greatly promote sugar production.

The publication of Margraff's investigations in 1747 led to experimental plantings of sugar beets throughout Europe. Vilmorin began beet cultural experiments in France in 1775 and the work has been continued by generation after generation of Vilmorins with distinguished scientific ability. They led the way in bringing the beet from a root of small and uncertain sugar content to one exceeding the cane in saccharine richness. Europe long bought her beet seed in France, but soon other

Photo Bureau of Plant Industry, U. S. Dept. of Agriculture
TYPICAL SUGAR BEET

countries followed the example of the Vilmorins and by various methods several varieties of very rich beets have been selected and their characteristics fixed. The beet, unlike the cane, is reproduced from seed and true to its parent characteristics. It is a biennial plant. There are many elements that enter into the selection of beets in seed production for commercial plantings. A study of these has led to the development of varieties true to type. The typical sugar beet is not of the usual garden variety, but is white, approximately top-shaped, free of side roots and weighs about a pound. It is only comparatively small beets that are rich in sugar. The growing of beet seed is a highly specialized industry and demands the services of thoroughly trained experts, familiar with the types and with every indication of atavism. Of the beets selected for seed growing on a basis of their superficial characteristics, a large proportion is rejected by the chemical tests. The selected beets must be true to type in every respect, and of a certain sugar content as is determined by polariscopic test of a small portion removed from a well-defined part of the root. The sugar is not uniformly distributed throughout the beet, but a certain zone has been found experimentally to carry about the average sugar content of the root. Beets so selected are grown from pedigreed seed and are termed "mothers." These are carefully stored over the winter and are planted in the spring. The seed obtained from them is sown to yield a crop of "mothers", which later produce the commercial seed, which is certain to result in rich beets.

Fiscal legislation has had a large influence in the development of the beet and the manufacture of sugar. France at one time taxed the sugar produced, and, as cattle feeding is an adjunct of the industry, large beets were grown which yielded little sugar and much pulp. Germany, on the contrary, taxed the beets themselves and at such rate that by growing very rich small beets the manufacturer obtained the equivalent of a bounty. Under such conditions Germany soon led in seed growing. France later placed the tax on the beet instead of the sugar and both countries, and in fact all Europe, became the home of a highly developed industry.

In cane sugar manufacture the juice is expressed by passing the cane between the horizontal rollers of a train of mills, consisting of one or two-roll crushers and upwards of six three-roller mills, arranged tandem. The crusher rollers are corrugated, or have V-shaped teeth, and their purpose is the disintegration of the cane

preparatory to milling. The crusher also expresses a considerable part of the juice. The cane passes between the rollers of the crushers and thence between those of the mills and is usually saturated with water after leaving each mill except the last. The residual material is termed "bagasse" and is conveyed directly to the boiler furnaces and meets nearly all the fuel requirements of the factory. An efficient milling plant extracts 95 per cent and upwards of the sugar of the cane. The rollers of the mill are arranged in a pyramid and the cane is crushed twice, once between the top and front roller and again between the top and back roller. The top roller is rotated by an engine through gearing and in turn drives the bottom rollers by crown-wheels. Two or three mills are usually driven by a single engine. The outlet rollers, or bagasse rollers, of the last mills of the train are placed against one another or "iron to iron". The top rollers are under hydraulic pressure, which varies with their position in the train and often exceeds 600 tons on a roller, seven feet in length. Such a plant, consisting of two crushers and six mills, will efficiently grind 150 tons of cane per hour. The residual bagasse amounts to from 20 to 30 per cent of the cane, the quantity varying with the woody fiber content of the cane and the efficiency of the grinding. The almost exclusive use of bagasse is as fuel, though a new industry in Louisiana manufactures wall-board from it. Its use in paper making has not been very successful.

The raw juice flows from the mill recipients to strainers for the removal of fine bagasse. It has an acid reaction and includes many substances in addition to sugar in solution. All except sugar are considered impurities. The cane contains three sugars: sucrose, dextrose and levulose, all of which are extracted with the juice. Cane juice, chemically speaking, s of very complex composition. Most of the impurities cannot be removed by commercially profitable methods and so pass through the process of manufacture and are found in the residual molasses. The raw juice is first nearly neutralized with milk of lime and is then heated to nearly boiling point in order to coagulate albuminoids and promote the lime combinations. A heavy scum rises to the surface of the juice and a precipitate settles to the bottom of the tank or defecator. After a period of rest, the clear juice, called "clarified" or "defecated" juice, is decanted from between the scum and precipitates. This is termed the "defecation process". There are numerous settling devices, but the principles of the process as described are preserved in all. The scums and precipi-

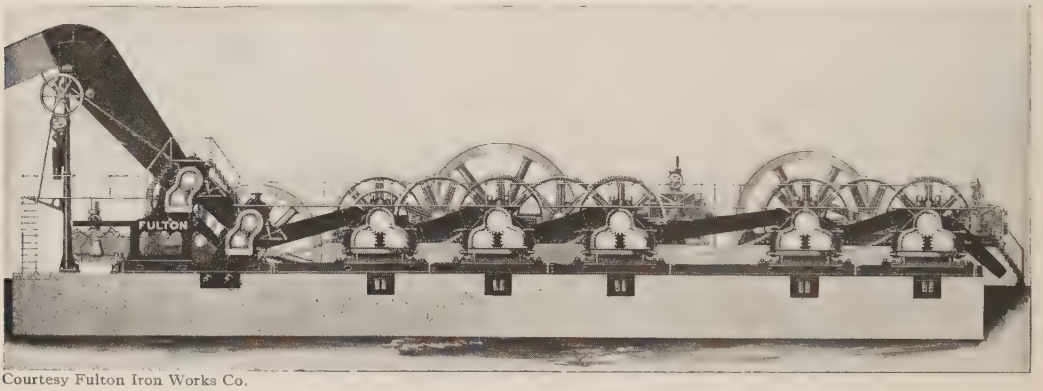
Photo Bureau of Plant Industry, U. S. Dept. of Agriculture
MOTHER BEET PRODUCING SEED

tates, or the "mud", are filter-pressed for the recovery of a large part of the sugar which they carry.

The clarified juice is conducted to multiple-effect evaporators for concentration to a sirup of about 65 per cent solid matter. A multiple effect evaporator consists of two or more vessels, operating under a partial vacuum, and so arranged that the vapor generated in one evaporates the juice in the next vessel, by reason of a progressively increasing vacuum. Steam is applied only in the first vessel. The apparatus usually consists of four or five

vessels or "pans" and is then termed a "quadruple-effect" or a "quintuple-effect". Juice is fed continuously into the first pan and sirup is constantly withdrawn from the last. In a quadruple-effect, for example, juice is boiled in the first pan with steam and the pressure in the vapor space of this vessel is about five inches of mercury. The steam generated in boiling the juice passes into the heating section of the second pan, the "calandria", and in boiling the juice in this pan is condensed, and so controls the pressure in the first vessel. The vapor generated in the second vessel is condensed in boiling the thickened juice in the third pan and a vacuum of about seven inches results in the second pan. The vapors generated in the third pan are condensed in the fourth calandria and a vacuum of fourteen inches is formed in the third vessel. The concentration of the juice is completed in the fourth pan, which is connected directly with a vacuum pump and a condenser for the removal of the vapors and the production of a vacuum of twenty-six inches or more. It is apparent that the steam applied in evaporating the water in the first vessel is used four times or with practically four times the evaporative effect than if used in a single vessel. The water of condensation is used in feeding the steam boilers and for various other purposes. There are still more economical combinations of vessels, but the principle of all is that described. Were it not for multiple-effect evaporation, the fuel problem of a sugar factory would be almost insurmountable.

The sirup from the evaporator is further concentrated in a vacuum pan for the crystallization of its sugar. This is necessarily accomplished in single-effect. A vacuum is produced in the pan by means of a pump and a condenser and sirup is then drawn into it and is evaporated by steam heat until supersaturated with sugar. Nearly microscopic sugar crystals now form in the boiling mass, the temperature of which, by reason of the vacuum, is about 150° F. The pan-boiler draws a test sample of this mass upon a plate of glass and from this judges how far to proceed with the formation of crystals. If he forms too many, the resulting sugar will be of too fine grain, and if too few, the crystals will grow too large and difficulty will be experienced in preventing new crystals from forming.



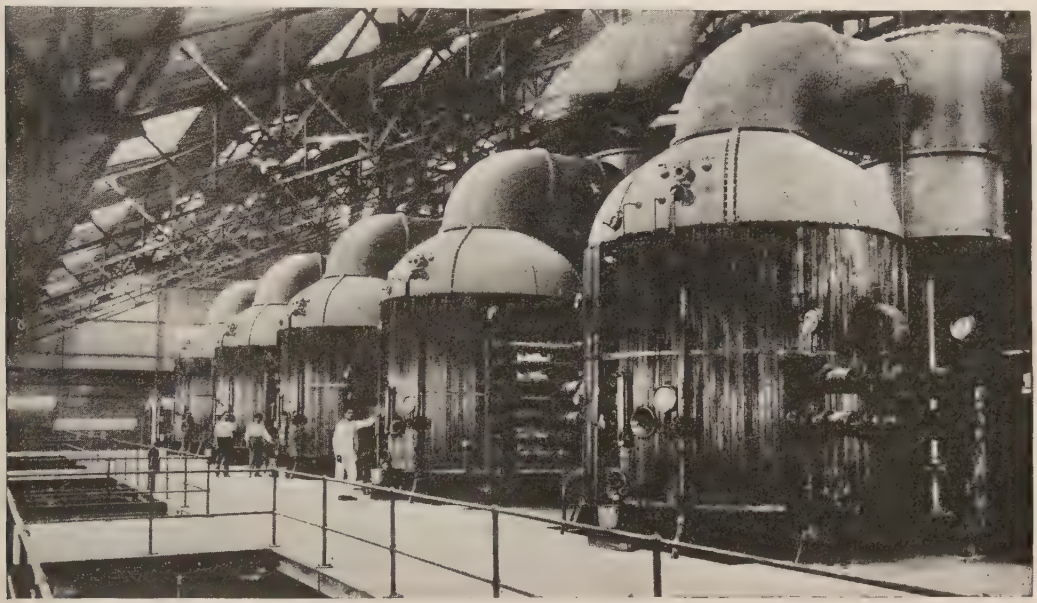
Courtesy Fulton Iron Works Co.

A FIFTEEN-ROLLER TANDEM CANE MILL WITH DOUBLE CRUSHERS

The pan-boiler so regulates the admission of sirup to the pan as to compensate for the water evaporated and force the sugar in solution to deposit on the crystals already present. By the time the pan is filled, the crystals will have grown to commercial size. The mixture of sirup and crystals, "massecuite", is now evaporated to a very dense mass, without further addition of sirup, and is then ready to "strike" from the pan. The steam and vacuum connections are closed and the vacuum is broken by the admission of air to the pan. The large foot-valve in the bottom of the vessel is opened and the "strike" is discharged into the mixer that feeds the centrifugal machines.

Briefly, the centrifugal machine of customary size is a cylindrical basket,

forty inches in diameter by twenty-four inches in depth, lined with a finely perforated metal plate, and suspended on an axial shaft, which may be rotated at high speed by a directly connected motor or a pulley at its upper end. The basket is suspended within a strong steel casing, having a molasses gutter at the bottom. The massecuite is fed into this basket, intermittently, from the mixer and is spun at about eleven hundred revolutions per minute. The centrifugal force presses the massecuite against the perforated plate, through which the sirup passes, leaving the crystals in a comparatively dry state.



Courtesy Joseph Oat & Sons

VACUUM PANS FOR BOILING SUGAR

These five 15-foot vacuum pans were constructed for the Central Delicias.

The sugar may be washed with a spray of water while the machine is revolving. The sirup or molasses flows off through the gutter. The sugar obtained in this way is commercially known as "centrifugal" and contains about 96 per cent of pure sugar. This product is shipped to the refineries for conversion into white sugar. The molasses obtained in purging the sugar is reboiled for another crop of crystals. This part of the process is rather complicated, as the molasses is not reboiled alone, but with liquors of a higher purity. Finally a low purity massecuite is boiled, largely of molasses from a reboiling, and this is discharged into crystallizers, large tanks fitted with mixing arms, where it is kept in motion for a few days while cooling, to carry the crystallization of the remaining sugar to the commercial limit. This massecuite is now centrifugaled and produces a low grade of sugar, which is either sold as such or is returned to the process for purification. The molasses from this low massecuite is very impure and is used in distilling and for cattle food.

In the direct production of white sugar from the cane, the process is similar to the above. The juice, however, is bleached with sulphurous acid gas before or after liming; and great care is observed to maintain an acid reaction and to remove all mechanical impurities by filtration through cloth. The low products, which are dark colored, are remelted in the juice and are retreated for color removal. The beet process, described farther on, is also used, with temperature modifications, in making white cane sugar in the factory. The white sugar is dried, after leaving the centrifugals, in "granulators" like those used in beet factories and refineries.

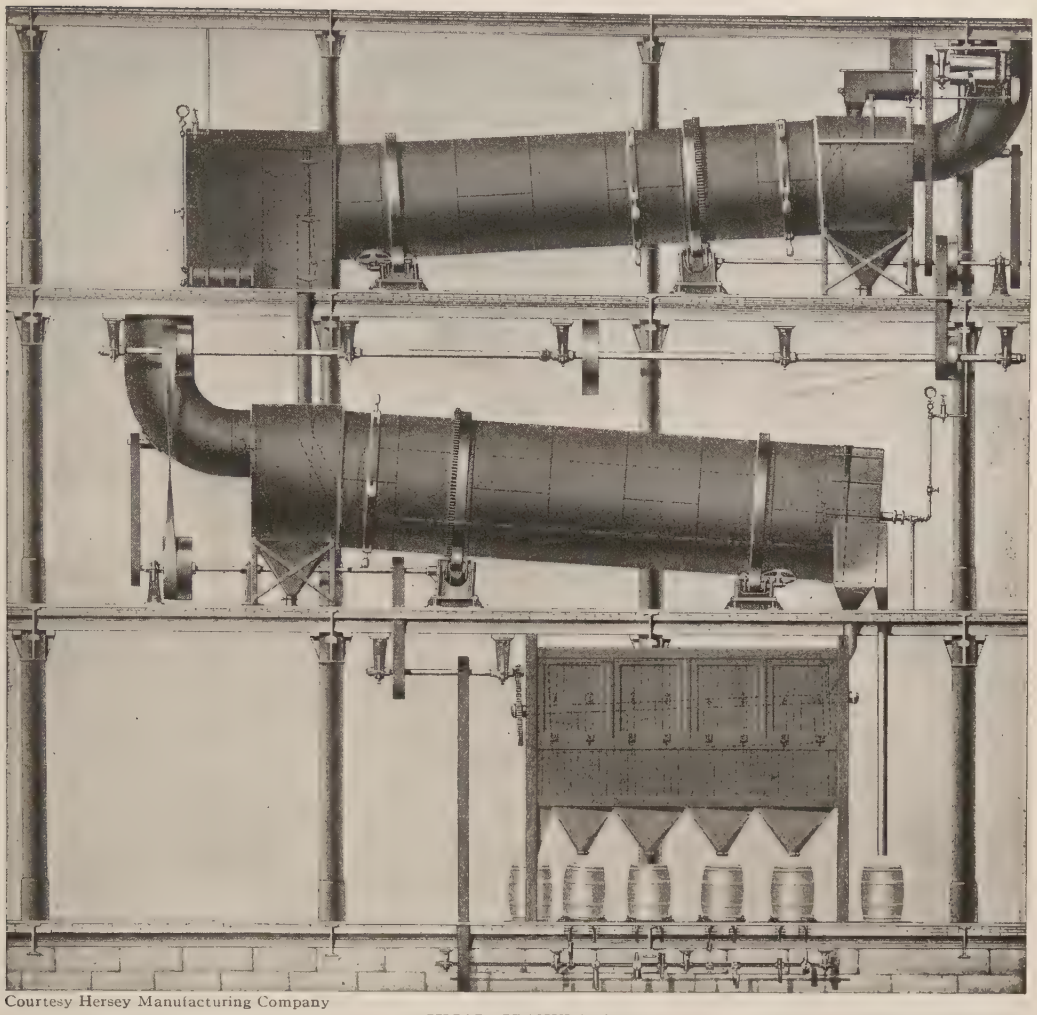
Turning now to the process of beet sugar manufacture, the beets are received by rail and highway and are stored in great

heaps in the factory yard while awaiting the manufacture of sugar. A system of narrow hydraulic conduits penetrates all parts of the yard. The beets are thrown into the conduits as required in the factory, and are swept by a swift current of water to the washers. Partly washed in the conduits, a thorough cleaning is effected in the washing machines, to which they are elevated. Here adhering soil and stones are removed and the roots then fall into the slicers. These machines cut the beets into more or less V-shaped slices, which are immediately conveyed to the diffusion battery for the extraction of their sugar.

In the early years of the beet industry, and largely up to 1876, the juice was extracted by hydraulic presses, but these are now obsolete, having been superseded by diffusion. This process depends upon osmosis or dialysis, that is, the property that crystalloids have in solution of passing through a membrane to an adjacent weaker solution or water. Sugar and many of the non-sugars of the beet are crystalloids and possess this property. In the diffusion process the wall of the juice cell of the beet furnishes the membrane. Since many of the plant cells are ruptured in slicing the beet, the process is not purely one of diffusion, but maceration enters to some extent. The diffusion battery is a series of twelve or more connected cylindrical iron vessels, or diffusers, in which the beet slices are bathed in water or thin juice, to which the sugar passes from the plant cell. The diffusers are arranged so that the first of the series always contains fresh slices and the last exhausted pulp. The liquid is forced to circulate through the battery by water pressure until the diffuser of fresh slices is filled, and then is continued, to draw a measured volume of juice which enters the manufacture. This diffuser now becomes second in the series and as the work progresses will finally be the last. The diffuser at the other end of the series contains exhausted pulp, which is discharged and conveyed to continuous presses to prepare it for cattle food. This routine continues at the rate of ten to fifteen or more diffusers per hour, the diffuser at the head always containing fresh slices and that at the tail the exhausted pulp. The temperature of the liquid is carefully regulated during the operations and all parts of the process are under rigorous chemical control. The pressed pulp is either siloed for feeding cattle, as required, or is dried and shipped for the same purpose. The dry pulp serves as a valuable absorbent for molasses and other liquid stock foods.

The raw juice flows from the diffusion battery to the carbonation tanks, where it is treated with a large excess of milk of lime, which is immediately nearly all precipitated by carbonic acid. If a saccharate process is used, which will be described later, lime saccharate is employed instead of lime and in sufficient quantity to absorb all the saccharate produced by the factory. This is the first carbonation and is followed by filter-pressing to remove the precipitates. The filtered juice is pumped through tubular heaters, in which it nearly reaches its boiling point, into a second set of filters, whence the clear juice flows into the second carbonation or saturation tanks. Without further treatment, except possibly the addition of a little carbonate of soda to help break up lime salts, the remaining lime is saturated with carbonic acid gas. The juice is again filter-pressed and the filtrate is sulphited for bleaching purposes, using the gas from burning sulphur. This is followed by another filtration. All the filtrations are through cloth. The resulting juice is of a light amber color, or nearly colorless, and is clear and brilliant. Brilliancy is essential in the manufacture of high-grade sugar. In the early days of the beet industry, a defecation process almost identical with that used with cane was employed, but the beet does not yield so readily as the cane, and the process was abandoned for carbonation. Notwithstanding the elaborate treatment described, the juice still contains many of its original soluble impurities. These persist throughout the manufacture and are found in the final mother liquor or molasses.

The purified juice is evaporated to a sirup as in the cane industry. The sirup is reheated, sulphited, again heated to



Courtesy Hersey Manufacturing Company

SUGAR GRANULATOR

Double drying system, with screens for removal of lumps and grading according to crystal size, and barrel-shakers or packers.

near its boiling point and then filter-pressed, after the addition of kieselguhr, or infusorial earth, to promote filtration. Finally this last filtrate is again filtered through cloth filters. This treatment of the sirup, made from highly purified juice, produces a clear, brilliant liquor which is suitable for the making of standard granulated sugar.

The succeeding stages of manufacture follow cane procedure, as already described. The crystallization is conducted in a vacuum pan and the crystals are freed of molasses in the centrifugals. The beet process described is for white sugar and in it the crystals are very thoroughly washed in the centrifugal machines with water. The sugar is discharged from the centrifugals into conveyors, which carry it to the granulators. A granulator is a long iron cylinder, supported in a nearly horizontal position on rollers upon which it is revolved, as above shown.

At the higher end of the cylinder is a suction fan which draws a current of air over steam coils and through the apparatus. Inside it, and extending its length, are narrow shelves. The sugar falls into the granulator at its higher end and is picked up by the shelves and then as the rotation continues it is dropped through the current of heated air, which carries off the moisture. This process not only removes the moisture but sepa-

rates the crystals from one another. By reason of the inclination of the cylinder, the sugar travels from the higher to the lower end and is discharged upon a rotating screen, where the dust and lumps are removed and the sugar is classified by the screen through which it passes. As has been explained, the size of the crystals is determined in the pan-boiling. In making raw beet sugar, the sulphitation and subsequent filtration are omitted. The sugar is not washed in the centrifugals.

The mother liquor, left after the crystallization of the sugar, is termed "molasses". This is not palatable and contains all the saline and other impurities of the beet. This by-product is used in distilling or as a cattle food. The sugar is often recovered from the molasses by a saccharate process. Sucrose, pure cane sugar, forms almost insoluble compounds with the alkaline earths as saccharates. The saccharates of lime, of strontium and, to a very limited extent, of barium are used commercially in removing sugar from molasses.

Crystallization cannot be further applied at this stage without employing a saccharate process, since the accumulated impurities prevent its use. The lime saccharate (Steffen's separation) process, is the one most frequently used. The principle of all of them is the same, however, the sugar being precipitated as a metallic compound. The lime process is conducted as follows:

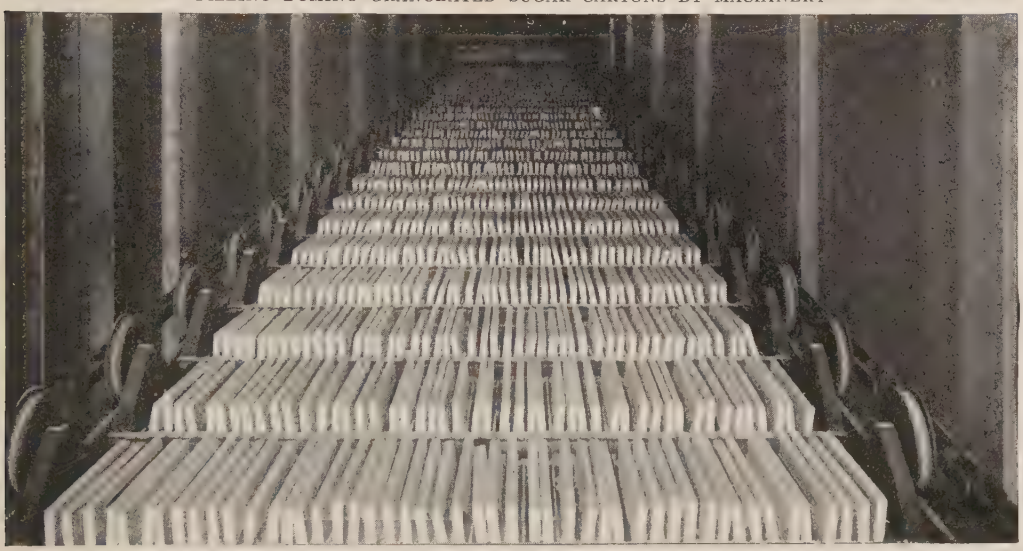
The molasses is greatly diluted with water and the solution rendered alkaline with lime to form the soluble mono-saccharate. This solution is now cooled in a special mixing and refrigerating device to about 54° F. Quicklime, in impalpable powder, is now added to the solution, little by little, with mixing and cooling to 54° after each addition, until a test indicates that all the sugar has been precipitated as tri-saccharate of lime, which is practically insoluble in water. The saccharate may be precipitated at other temperatures, but that formed at this low temperature may be readily separated from the liquid by filtration. The mixture is now pumped into filter presses, where the precipitate is collected and washed with cold water. A part of the washings is used in diluting fresh batches of molasses and the remainder, with the mother liquor, is heated to near the boiling point. This heating results in an additional precipitation of the tri-saccharate which is recovered in filter presses. This saccharate could now be suspended in water and decomposed with carbonic acid gas, leaving the sugar in solution and the lime as an insoluble carbonate. The usual procedure is to use the saccharate in liming the juice in its purification, thus effecting a large economy of lime and carbonic acid. The beet sugar factory obtains its lime and carbonic acid in calcining limestone and makes up any deficit of the gas by withdrawing this from the chimneys.

The sugar that reaches the consumer is usually refined in special establishments, economically located on the seaboard for the receipt of raw sugar and supplies. These refineries treat either raw cane or beet sugar by special processes for color removal. It has been explained how the factories produce a white product directly from the raw materials. This is only feasible under certain conditions, such as those which result in practically only white sugar production in the American beet factories. These refineries operate upon an enormous scale, by a very economical process, and are in close touch with all that affects the production and distribution of sugars. It is probably usually less costly to produce raw sugar in a factory and refine it in a special establishment. The world's largest refineries are located within the United States.

Refineries are conveniently located for the receipt of raw sugars directly from the ships. The sugars are purchased upon a basis of their polarization or sugar content, as is determined by means of a polarimeter or polariscope. This is an optical instrument in which a ray of polarized light is passed through a sugar solution of definite column length and concentration. The ray of light is deviated, or its plane of polarization is rotated, in proportion to the sugar content of the solution. This rotation is measured by an optical device and is translated into percentage

DRYING AND PACKING FINE TABLE SUGAR

FILLING DOMINO GRANULATED SUGAR CARTONS BY MACHINERY



DOMINO TABLET SUGAR IN DRYING OVENS

Courtesy The American Sugar Refining Co.

PACKING AND SEALING DOMINO TABLET SUGAR

terms of cane sugar. This is the instrument that is used in analyzing sugars in fixing the customs taxes, and in the factory and refinery laboratories in the control of the processes of manufacture. The usual market basis in the purchase and sale of raw cane sugars is a polariscopic test of 96 degrees or per cent. The basis for beet sugar is similar, though account is taken of its more intractable impurities.

The raw packages are opened and the sugar is dumped into a conveyor. This conveys it to a mingler, where it is mingled with sirup to form a thick magma, similar in appearance to a massecuite. This magma is purged in centrifugal machines such as are used in the factories, and the resulting sugar is liberally washed with water. The sugar is of a very light yellow color and high purity and is similar to old-fashioned brown sugar. This process is termed "affining" or "washing" and permits the refiner to separate his material into a high purity raw sugar and a sirup containing most of the impurities. This is a very important part of the process of refining, since it facilitates the simultaneous working of sugars of different grades. The washed sugar is discharged into melters, where it is dissolved to form a heavy liquor, and is pumped to steam blow-up tanks to be prepared for filtration. The washings are partly used in preparing fresh batches of magma and are largely pumped to blow-ups for separate treatment.

It is essential in refining that the sugar solutions be perfectly clear and brilliant. There are several methods of attaining this condition. The following is a very common modern method: To the washed sugar liquor is added lime to neutralize its acidity, and then a small quantity of kieselguhr. The mixture is heated in the blow-up to about 180° F. and is then filtered through a special type of cloth filters. The filtrate is of a light yellow color and is very brilliant. It is now ready for the bone charcoal filtration. The raw sugar washings are similarly treated, except that a different type of filter is used. Separate subsequent treatment of the two solutions continues until they have approximately the same color and purity.

The clear liquors are next filtered through bone charcoal, in deep cylindrical iron filters. The liquor is passed through the charcoal for a definite time and then sugar washings are substituted for it. The filtered liquor is water-white, the charcoal having absorbed the color and many of the impurities. After the charcoal ceases to sufficiently decolorize the liquor, it is washed thoroughly with water while in the filter to recover the sugar it holds, and is then conveyed to the drying-floor above tubular kilns. The char is reburned in these kilns and leaves them revivified and ready for reuse. These manipulations are repeated indefinitely, with a very small loss of char at each operation.

The white, filtered liquor is evaporated in a vacuum pan for the crystallization of the sugar as in the factories. The massecuite or magma is purged of sirup in centrifugal machines, in which the sugar is thoroughly washed with water. The sugar is dried in a granulator as has been described for beet sugar. The sirups are reboiled for sugar so long as color admits, and are then refiltered through charcoal and again reboiled. Finally the mother liquor is too impure and highly colored to produce white sugar and is then reboiled to make a raw sugar for refining. Two grades of this raw sugar are usually made, a high and a low "remelt sugar". The final molasses residue, "barrel sirup", is sold as such or is diluted with water, char filtered and reconcentrated to make a sirup for the baking and other industries. A high-grade sirup is sometimes made for the groceries.

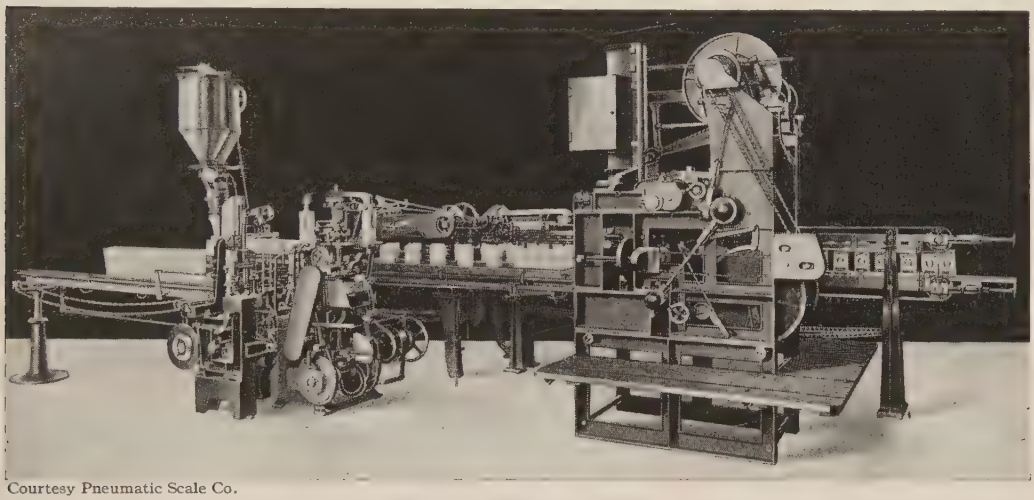
There are many grades and forms of refined sugars on the market, a few of which are of especial interest. Cubes and tablets are molded from sugar moistened with white sugar liquor, and dried in special ovens. Cut tablets — Crystal Dominoes — are made by the Adant process. Very brilliant crystals are "boiled" in the highest quality of white liquor and the resulting magma is run into molds in a special type of centrifugal machine. The sirup is spun off and the crystals are washed in the machine with a pure concentrated solution of sugar to displace the remaining traces of sirup.

The molds are transferred to an oven, where the slabs of sugar are dried. They are then sawed and cut into tablets, which are carefully sorted and only the perfect ones packed in cartons. Powdered sugar is made by grinding granulated sugar. The finest "confectioners'" grade is sifted through silk bolting cloth. The yellow and brown grades of refined sugar are made from the sirups that have not been filtered through animal charcoal for color removal.

The methods of packing granulated sugars in a refinery are of interest. The sugars are weighed automatically, whether packed in sacks or cartons. The touch of a key on the hand-operated scales delivers a weighed charge of sugar into the sack, which is then conveyed by an endless belt to the sewing machine for closing. In packing in cartons the machine picks up a "blank" from a pile, shapes it, lines it and pastes down the flaps, leaving an end open for filling. It next carries it to a preliminary scale where approximately the correct amount of sugar is weighed into it, and then to a second scale to accurately complete the weight. The full carton is now passed to a device that turns in the top flap and seals the finished package, which is delivered by a conveyor alongside the packers who place it in boxes. The covers are nailed on by a machine and the boxes are then conveyed mechanically to the warehouse ready for distribution.

Sugar is almost never touched by the hand in the whole process of manufacturing and refining. When well-refined, it is practically chemically pure sucrose, containing only about one-tenth per cent of impurity, almost entirely moisture.

The following statistics will show the growth of the sugar industry in its efforts to meet the increasing demands for sweets. In 1901, the largest factory produced about 30,000 tons of sugar and a few others followed with a production of less than 20,000 tons. In 1922 a single plantation in Cuba made about 250,000 tons of sugar in two factories and about 170,000 tons in one. Several factories are making about 90,000 tons of sugar annually. These figures are significant when compared with a total production of 240,000 tons in Louisiana and Texas in a full crop, or 200,000 tons in the British and French West Indies, 250,000 tons in San Domingo and 900,000 tons in all of South America. The conditions of the beet industry do not lend themselves so well to such concentration of production as do those of the cane. There is no danger of a sugar shortage, for there are very large areas of land still left in the tropics for cane and a vast area for beets is still untouched.



Courtesy Pneumatic Scale Co.

SUGAR PACKING MACHINE

This is the type of equipment used to make up the 2-, 3½- and 5-pound cartons of sugar found on the grocers' shelves. The operation includes taking the printed cartons as received from the lithographer, opening them, sealing the bottoms, inserting a paper bag liner when necessary, weighing and filling the sugar into the carton, closing the top flaps and sealing — all without the aid of an operator.

LEADER AND HISTORIAN OF HIS TRIBE

Among uncivilized peoples the old man retains his power because he is the wise man, or the preserver of the traditions and customs of the tribe on which prosperity is believed to depend.

1882

THE ORIGIN OF KINGSHIP

How the Magician of Savage Races Became
a Wizard Chief, and Then a Royal God

SUPERSTITION AS A SOCIAL FORCE

THE ordinary Englishman of today would smile at the suggestion that his king is descended from a god. George V is a modest person and lays no claim to any of the qualities of the heathen deity Woden, whose name we preserve in our word "Wednesday" or Woden's day. He does not even touch for King's Evil, as Queen Anne touched Dr. Samuel Johnson. No doubt he would say, as William of Orange said when a man flung himself at his feet praying to be healed by the royal touch, "God give you better health and more sense." Yet ancient records enable us to trace back the English kings to the pagan days when they mightily prided themselves on the fact that they were human gods, with Woden as their not remote ancestor.

The emperor of Japan is a man of as much common sense as the king of England. But he, too, is the descendant of a deity. In his case, the sun-goddess very graciously came down to earth and formed some savage tribes into a nation, and governed them, the first mikado being her child. Every emperor of Japan was worshiped by his people as an incarnation of the sun-goddess. Up to the middle of the nineteenth century there was one month in the year in which nobody frequented any of the Japanese temples. It was useless, because all the shrines were deserted by the gods. They were spending a month at the court of the mikado, and humbly waiting upon him and paying reverence to him in his divine capacity.

It is well known that the emperors of China were considered the sons of heaven. One reason why the Manchu usurpation has now ended in the foundation of a republic is the fact that the strange new line of northern barbaric chiefs had no superstitious hold on the popular mind. The history of their conquest of the throne was much too recent for them to revive effectually the ancient tradition of the divinity of the sovereign.

This tradition has at one time or other been practically universal in monarchical governments. The early Babylonian kings, from Sargon to the fourth dynasty of Ur, claimed to be gods in their lifetime. The ancient kings of Egypt were worshiped as sons of the sun-god, and so were the emperors of Peru. The earliest kings of Rome were earthly Jupiters — sons of the god of the sky and the thunder and the oak-tree. Less is known about the primitive kings of Greece, but that little goes to indicate that they were persons with supernatural attributes. In fact, all the Aryan races from India to Ireland were originally governed by rulers who were supposed to possess divine powers, by means of which they could make the earth fertile and alter in various ways the course of nature. The deification of the Roman emperors, which caused such scandal among the early Christians and led to their persecution, was not an extraordinary circumstance. On the contrary, it was only a revival of one of the commonest customs of primitive monarchy.

It is difficult for us to understand it, for the reason that our ideas of Divinity greatly differ from the ideas which the pagan races of the world still retain on the subject.

They cannot rise to our conception of a Divine Power of a purely spiritual nature. Some savage tribes have, it is true, a notion of a Divine All-Father, but they regard Him as a kindly human ancestor who has been exalted to the spirit world. Their idea of the universe is so narrow and childish that they cannot get beyond the idea of a ghostly magician of a benevolent nature. In short, their gods are ghostly magicians, their magicians are living gods.

It must be remembered that every savage is, in his own opinion, endowed with tremendous powers. All that the man of science now dreams of accomplishing, the savage has for hundreds of thousands of years calmly assumed that he achieved by means of magic. The wild wonders that happen in our genuine fairy-tales are traditions of the childhood of our race, when man lived in a world of mystery which he thought he could mold to his heart's desire by babyish rites of magic. Such was the mental atmosphere in the days the wizard welded tribes into kingdoms.

The secondary place filled by fighting-men in superstitious tribes

Before Professor J. G. Frazer completely revolutionized our ideas of the origin of the higher forms of government, it was generally assumed that brute force had prevailed in the making of the earliest nations. Undoubtedly the warrior has been a constructive force in human affairs; and in a previous part of this work we showed how much the sword has done in consolidating mankind, introducing new elements of culture among backward races, and enforcing the coöperation necessary for progress to civilization. But in the earliest societies the fighting-man is often less potent than the magician. Not by force of arms but by the power of superstition is government maintained in the rudest of existing social groups representing primitive man.

The blackfellows of Australia, for instance, are not ruled by their best fighting-men, but by very old wizards. The social organization is loose, and it has often been mistaken for a primitive democracy, with neither chiefs nor kings. But as a matter of fact it is a harsh and tyrannical oligarchy of old men. It is a government by elders; and the headmen undertake the task of performing magic ceremonies for the multiplication of various animals and plants on which the clans live. In short, most of the headmen are magicians who are assumed to provide the people with food. Others have to cause rainfall and render similar services.

How men careless of bodily harm succumb to ghostly fears

They are public wizards. Their most important function consists in taking care of the sacred storehouse, usually a cleft in the rocks or a hole in the ground, in which are kept the holy stones and sticks of the tribe. With these stones and sticks the souls of all the people, living or dead, are bound up. The wizard calls the tribesmen together for initiation ceremonies and public discussions. In fact, he is a chief in all but name, and if he aspires to great influence he must be a skilful conjurer. For some tribes in southeastern Australia have reduced the test of all candidates to headmanship to a simple matter. The greatest headman, according to their way of thinking, is found in the man who can produce the largest number and variety of things from his inside. A "magician" like Houdini would easily defeat a Cæsar or Napoleon in a contest for the chieftaincy of any of the lower savage tribes.

This will at once be clearly understood if considered from the point of view of the savage. He does not fear any bodily hurt. Many savage races are continually engaged in warfare. Every expansion of population leads to quarrels about territory, which end at last in the ordeal of battle. As a rule it is the young fighting-men who are most eager to resort to the use of force; and if there were no means of keeping them in check, they would rebel against the authority of the old men.

It is here that the influence of the tribal wizards tells. Taking a cunning advantage of the wildly superstitious nature of the savage, they rule him by ghostly terrors and magic customs until he cannot, literally speaking, even call his soul his own.

They can raise up ghosts to haunt him, cast awful spells upon him, and even make him waste away like a wax image before a fire. And all this can be done secretly, so that the punishment falls in a sudden and mysterious manner without any warning. What is the power of a man who can throw a spear or use an ax a little quicker than his fellows, compared to the ghostly abilities of a magician? When the matter is looked at in this light, the marvel is not that kingship largely arose out of wizardry, but that any warrior chief of a later date ever succeeded in subordinating the witch-doctors of the tribe.

The difficulties of usurpation in lands where superstition reinforces kingship

In New Guinea the level of culture is higher than it is among the blackfellows of Australia, but many of the races are still unorganized into chieftainships. Now and then, however, some renowned wizard manages to get into the position of a temporary king. Wars, marriages, deaths, raids and fishing and hunting expeditions are all under the dominion of the magician. For nothing would prosper unless he had been consulted about it, and given offerings to perform the rites that bring success. He is the master of life and death and so he is feared and obeyed in everything he demands in a way that no man relying on mere force could command.

One man of the Taoripi tribe of British New Guinea has been made a chief because he can rule the sea, calming it or rousing it to fury at his pleasure. Another owes his power to his skill in making the rain fall and the sun shine, and compelling the trees to bear fruit. The present chief of Wedau is also famous as a rain-maker and a wind-controller. In this stage of society the road to power is open to all the talents. Everybody practises magic and believes in it, but some men have more self-confidence than others. Perhaps they are more intelligent and less impressionable than the majority of their fellows; anyway, they grow bold enough to lay claim to the possession of supernatural powers of an unusual nature, and succeed in convincing the people they possess them.

Where chieftainship depends on direct inheritance of magical powers

Such seems to be the method by which some sort of central authority is obtained by an able and cunning man among the lowest races now known to us. When ancestor-worship develops into something like religion, the wizard chief is often able to hand on his authority to one of his sons or male relatives. In some of the South Sea Islands, for example, the power of the chiefs rests on the belief in their spiritual and magical genius, and this genius is derived from the spirits of ghosts with whom they have intercourse. In any case of difficulty they are able to bring down on their enemies the influence of the spirits. If a chief imposes even an unjust fine, his people pay it, because they are afraid that if they anger him he will bring a plague.

In one of the New Hebrides there is a nobility which, like most primitive aristocracies, is founded upon wealth. But the wealth is used in a very curious way. Those persons who have been able to afford it have sacrificed a thousand little pigs to the souls of their ancestors. Nobody dares in any way to resist a man who has carried out this sacrifice. For in him are supposed to dwell all the souls of the ancient chiefs and all the spirits who preside over the fluctuating fortunes of the tribe.

The spiritualistic medium of the modern era who asserts that he is on terms of familiar intercourse with Julius Cæsar and Mahomet and the rest of the mighty dead possesses many of the advantages of a New Hebrides nobleman, but our incredulity prevents him from making the best of his very aristocratic connections. Had he lived two thousand years ago he might, if circumstances had favored him, have become the king of his tribe. Had he then possessed some military talent in addition to his spiritualistic ability, he could have gone forth to conquest and founded a nation.

As a political instrument, the apparatus of a magician is more useful than the ax of a warrior. A soldier chief of primitive or savage race cannot always make sure that his descendants will inherit his powers.

They may be only young men, and not so strong of body and full of courage as he was; and their claim to the leadership may be disputed by some older man with more experience and fame in war. In the absence of any superstitious reverence for the offspring of a self-made leader, a nation would probably be destroyed by tribal and personal jealousies and ambitions long before its internal industrial development so consolidated it that it could survive recurring periods of anarchy. Where, however, something of the prestige of magical power still attaches to the kingly office, kingship can descend from father to son.

In northern New Hebrides, for instance, a son does not directly inherit the chieftainship; but as he knows his father's magical incantations and possesses his sorcery stones and other magic instruments, he is usually able to succeed to the office. Moreover, the son of a wizard chief is often regarded by savage people as an incarnation of the father. As soon as the father dies, his spirit enters the body of the son. What becomes of the soul of the son in this case is a matter of which we have no knowledge. The superstition, however, is very useful in maintaining the continuity of a central power of government and preventing usurpation and disorder.

As we have seen, the mikados of Japan are successive incarnations of the sun-goddess. So when a soldier usurped the kingly power during the wild feudal wars, the sacred person of the monarch had to be respected.

THE DIVINITY OF KINGS — THE OBEISANCE OF THE NOBLES TO THE MIKADO OF JAPAN

The victorious usurpers maintained their power over the popular mind only by imprisoning the mikado, and pretending that he was so holy that he could not be seen, and thus could only act through them. They professed to be humble servants of the royal god — in somewhat the same way as the usurpers of power in Tibet shielded their "eternal and heavenly father" from the public gaze — and they carried on the government ostensibly as his human servitors.

The way was thus left open, through all the disorders and civil wars of Japan, for the mikado to assume full and direct authority when the chiefs of the clans awoke to the fact that their country was endangered by their jealousies and jarring ambitions.

Usurpation is always difficult in a primitive monarchy. It means, looking at the affair from a primitive point of view, no rain, no crops, cattle sickness, and a plague among the people. All the spirits of the dead chiefs conspire to punish the nation, and no ordinary magician can prevail to avert these disasters against their combined efforts.

When, in ancient Ireland, Carbery Kinncat usurped the throne, the chroniclers relate that only one grain grew on every wheat stalk, and no cow gave any milk. In Scotland, the stone on which a king sat to be crowned showed if he were not of the royal race. It is now used in Westminster Abbey at the coronation of the ruler of the British Empire, but it has apparently lost its power of speech.

People who regard the royal regalia as a wonder-working talisman

The regalia of royalty may very likely be derived from the instruments of magic that the wizard chiefs of old bequeathed to their descendants. We have already seen that the symbols of a great sorcerer are still very effective in enabling his son to assume authority over a savage tribe. In the Indian Archipelago the regalia are regarded as the fount of regal dignity. In southern Celebes the royal authority is even supposed to be embodied in some mysterious fashion in the symbols of kingship. The princes owe all the power they exercise, and all the respect they enjoy, to their possession of these precious objects. In short, as Professor J. G. Frazer remarks, the regalia reign, and the rulers are merely their representatives. So whoever happens to possess the regalia is regarded by the people as their lawful king.

If a deposed monarch contrives to keep the sacred insignia, his former subjects remain loyal to him in their hearts. His successor is merely a usurper, and obeyed only in so far as he can exact obedience by force. So the first aim of rebels in any insurrection is to seize the regalia; and if they are successful the authority of the sovereign is gone. Temples are built for the regalia to dwell in, just as if they were living creatures, and furniture, weapons and even land are assigned to them. In times of disaster they are brought forth as instruments of magic for the purpose of staying the evil. Sometimes the regalia consists, like the instruments of the savage magician, of stones and pieces of wood and curious dried fruit. When a missionary asked to see some of these objects, the native guardian replied that if he were to open the bark-cloth in which they were wrapped there would be an earthquake!

Thus in the Malay region the regalia are still merely wonder-working talismans which the modern king seems to have inherited from the ancient magician. So we may conjecture that in other parts of the world the emblems of royalty may have had a similar origin. In ancient Egypt, for instance, the two royal crowns, one white and one red, were supposed to be endowed with magical qualities. They were divinities, being, like Pharaoh, embodiments of the sun-god. Sometimes the guardianship of the magician instruments is a source of great inconvenience to the wizard chief.

A few years ago the headman of Etatin, on the Cross River in southern Nigeria, was an old man whom the people had compelled to take office in order that he should look after the fetishes or "ju-jus," and work magic for the benefit of the community. In accordance with an ancient custom, which is binding on the head chief, he was never allowed to leave the inclosure in which his house stood. He gave the following account of himself to a foreign visitor.

"I have been shut up ten years, but, being an old man, I don't miss my freedom. I am the oldest man of the town, and they keep me here to look after the 'ju-jus,' and to conduct the rites celebrated when women are about to give birth to children, and other ceremonies of the same kind. By the observance and performance of these ceremonies I bring game to the hunter, cause the yam crop to be good, bring fish to the fisherman, and make rain to fall. So they bring me meat, yams, fish, and other offerings. If I were to go outside this compound, I should fall down dead on returning to my hut."

Control of the elements one of chief duties of a primitive king

The kings of Mexico took an oath when they were crowned that they would make the sun shine, and the clouds give rain, and the rivers flow, and the earth bring forth abundantly. Such were, indeed, the chief duties of a primitive king. The Chinese emperor has always held himself personally responsible for very severe droughts and many self-condemnatory edicts in this matter used to appear in the Peking Gazette. The rulers of Korea and Tonquin were also blamed for bad harvests, typhoons and epidemics. When things were very bad, the Tonquin king changed his name. If that did not remedy matters, he transferred the kingship to his brother or son, or some near kinsman.

Kings of olden times even sacrificed for failing to ward off famine

The office of a king certainly had some amazing disadvantages in primitive days. A magician who could not work magic at the proper time was often in danger of losing his life. The fact that his people were too profoundly superstitious to dream of questioning his powers only increased his peril in adverse circumstances. A succession of bad harvests never showed that the royal art of rain-making was an imposture. It only convinced the people either that their king was spiteful and bent on doing harm to his subjects, or that the spirits were punishing the people because they did not get a better king.

The Edonians of Greece put their king, Lycurgus, to death during a very bad harvest. The Burgundians usually deposed their rulers whenever the crops failed; and in a famine the Swedes sacrificed King Comalde to their gods. The Scythians put their king in bonds when food was scarce, and did not release him until he relented and worked the magic that made the people happy. More chiefs and kings throughout the world have fallen because rain did not come at the proper time than have been deposed because of any sound political reason.

There are, indeed, cases where a change from monarchical government to republicanism has been brought about entirely by superstition. On Savage Island formerly reigned a line of wizard kings who were supposed to make the food grow. But a succession of bad seasons set in, with the result that the kings were killed one after another, till at last no one would undertake the office of kingship. So the monarchy came to an end.

The dangerous honor of a kingship depending on health

It is still not uncommon to find among savage and barbaric races another strange peril attaching to the kingly office. The magician first climbs to chieftainship, and then acquires divine qualities. To the mind of a savage, the difference between a powerful sorcerer and a god is not clear. His gods are often merely hidden magicians. So he is ready to regard his kings as human gods, and to obey them with extraordinary humility. A god, however, must not be subject to human maladies. At the present day many petty kings of Africa are bound in honor to commit suicide as soon as they feel themselves to be ill. So much depends upon the royal magicians being in a fit state to exercise their supernatural powers that their health becomes a matter of supreme national importance. Strange ordeals have been employed to test the continued strength of the king. There have been many monarchies in which at stated periods the ruler had to engage in a deadly combat with any man who cared to fight for the crown. The earliest kings of the Roman people, for instance, had to enter once a year a sacred grove, and fight against any rival. And in India, as late as 1743, the king of Calicut had either to cut his throat in public at the end of a reign of twelve years, or to stand on a ridge, at some distance from the temple, and fight continually for twenty-eight days against the best of his youngest swordsmen.

How the ordeals on which kingship depended have been evaded

Generally speaking, the primitive kings of the world were able to surmount the difficulties which they created for themselves by their pretension to magical and divine powers. Men of masterful character merely used at last the magician's wand to clear the way to the throne. Having won it, they maintained themselves by the power of the sword, and reduced the annual fight or other periodical ordeal to the empty form it often assumed in historic times. The kings of Rome, for example, avoided the sacred grove, and appointed some criminal to be the annual king of the wood, and the custom became a yearly conflict between malefactors and outcasts. And the king of Calicut, when the twelfth year of his reign arrived, took his accustomed station on the bridge but surrounded himself with forty thousand fighting-men. No swordsman ever cut his way through the long barrier of spears.

How rulers sometimes evaded responsibility for control of the seasons

The responsibility for the control of the seasons and the supply of food was evaded, in many cases, by delegating the functions of looking after the weather and the health and prosperity of the people to a class of subordinate magicians, like those that Moses encountered at the court of Pharaoh. Moreover, in most of the earliest civilizations the practices of totemism and fetishism developed into a system of idolatry. The animals which the primitive magician of the tribe once had to make to flourish were raised to the rank of gods, and left to look after themselves. If they did not attend to the wants of the people in spite of the prayers and sacrifices offered up to them in seasons of drought or plague, their images were taken from the temple and beaten and dishonored.

The rise of royal despots beneficial compared with savage wizardry

All this saved the persons of the kings, and enabled them to kick away the ladder by which they had climbed to the throne. Giving up the use of the black art, without, however, relinquishing their "divine rights", they became priestly despots, and, as such, they emerge into the light of history. The general result of the evolution of the savage wizard into a royal despot was to place the supreme power in the hands of men of the keenest intelligence and the most unscrupulous character.

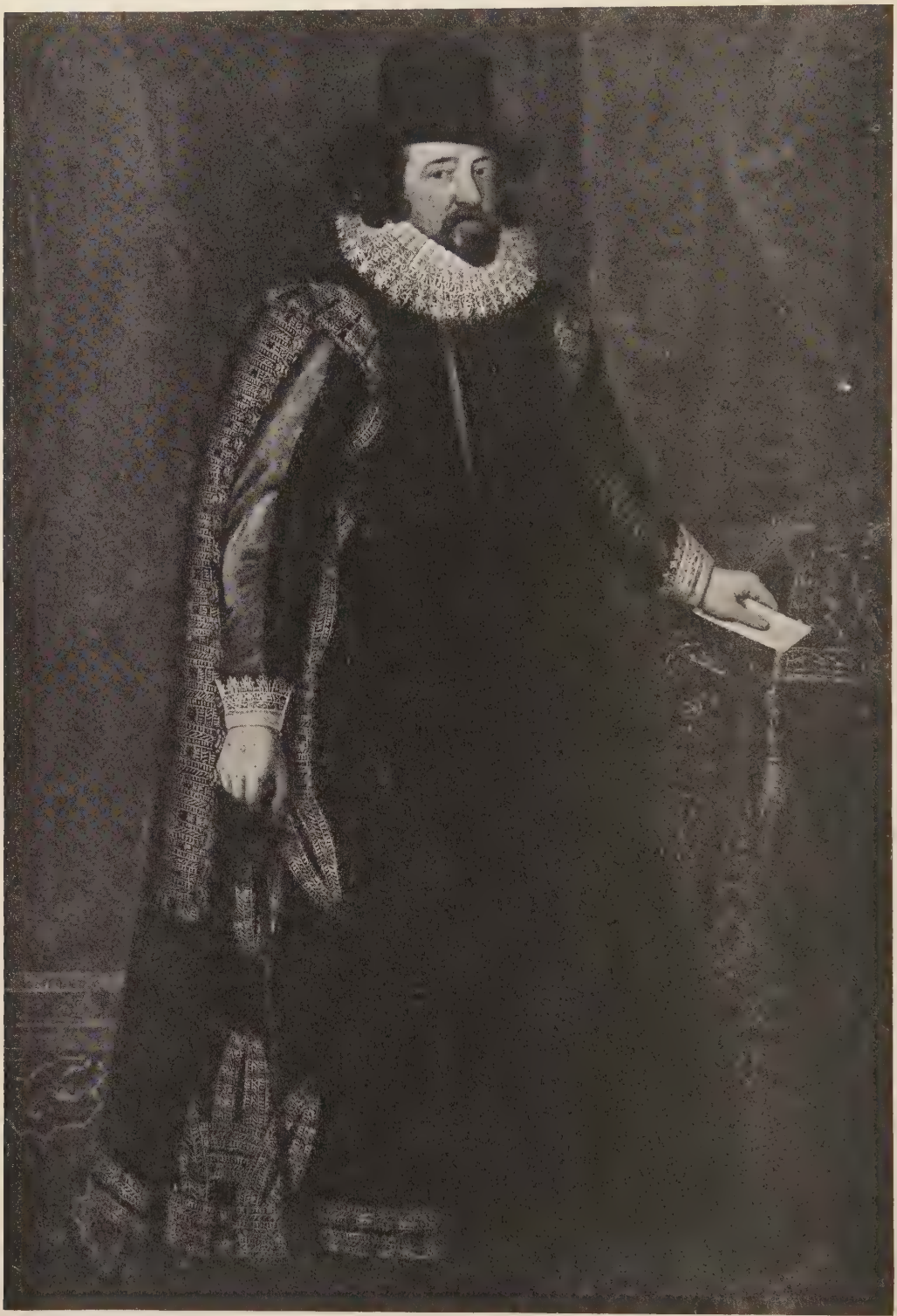
The change from the primitive oligarchy of old men — all of them magicians — to a monarchy in which the rule of a single ruler prevailed was, on the whole, beneficial. As Professor J. G. Frazer remarks, no human being is so hide-bound by custom and tradition as the apparently democratic savage. He is a slave, not, indeed, to a visible master, but to the past — to the spirits of his ancestors, who guide his steps from birth to death, and govern him with a rod of iron. In no other state of society is progress so slow and difficult. Scarcely any scope is afforded for men of superior talent to change old customs for the betterment of the community.

First great strides toward civilization made under despotic governments

From this low and stagnant condition of affairs, the cunning magician uplifted his duller-minded fellow-men by playing on their superstitious fears. The rise of one man to supreme power enabled him to carry through in a single lifetime changes which many generations might not previously have sufficed to effect. It is not an accident that all the first great strides towards civilization were made under despotic and theocratic governments, where the supreme ruler received the servile allegiance of his subjects in the double character of a king and a god. At this early epoch the despot often was a liberator. Under the most grinding of early tyrannies there was more liberty of mind and soul than under the apparent freedom of savage life, where the lot of the individual from cradle to grave was, and is, cast in the iron mold of hereditary custom. Here is the conclusion formed on the matter by Professor Frazer:

"So far as the public profession of magic has been one of the roads by which the ablest men have passed to supreme power, it has contributed to emancipate mankind from the thraldom of tradition, and to elevate them to a larger, freer life, with a broader outlook on the world. This is no small service rendered to humanity. And when we remember further that in another direction magic has paved the way for science, we are forced to admit that, if the black art has done much evil, it has also been the source of much good; that if it is the child of error, it has yet been the mother of freedom and truth."

Of course, other factors, beside superstition and wizardry, concurred in the evolution of the earliest forms of government. There was, for instance, the terrible ordeal of battle, which acted as a selective agency between neighboring but quarrelsome groups. If superstition weakened a people instead of giving it more cohesion, that people became broken up in the next period of fierce warfare. Thus the power of wizardry was somewhat checked and directed by interaction with other social forces.



FRANCIS BACON AS LORD CHANCELLOR, FROM THE PAINTING BY VAN SOMERS
This photograph of the portrait in the National Portrait Gallery is by Emery Walker

THINKERS II

AVERROES — CELEBRATED ARABIC PHILOSOPHER
FRANCIS BACON — "THE WISEST, BRIGHTEST, MEANEST OF MANKIND"
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AVERROES
Celebrated Arabic Philosopher

ABU'L WALID MUHAMMAD IBN-AHMAD IBN-MUHAMMAD IBN-RUSHD (*i.e.* the son of Rushd), called Averroes by the Latins, was born at Cordova in Spain, in 1126, of a family important in the political life of Andalusia. His father was cadi (judge in civil actions) there, and at his death the son succeeded him in his post, as he had his father. Averroes, in accordance with the tradition of his family, studied jurisprudence and theology, and later physics, astrology and mathematics. Called to Morocco by the caliph Yusef al-Mansur, he reformed the administration of justice in that country and, returning to Cordova after a brief stay, began to teach the principles of his philosophy.

Speculative studies were all regarded with distrust and anyone deemed an infidel to Mohammedanism who was not content to accept the natural science of the Koran. Denounced to the caliph as a heretic, dismissed from his post, his goods confiscated, he found himself compelled to flee. He hid in Fez for a time, but was discovered, imprisoned and condemned to make apology. After a while the storm passed, and he was able to return to Cordova, where he lived in poverty, deprived even of his books. But his merits were too great for him to remain long in oblivion, and he was recalled to Morocco by the caliph and reëstablished in his former magistracy. But he lived only a short time, dying in 1198, a year before his patron.

He left no school and his reputation, which had spread to the East during his lifetime, ceased with his death. It was, above all, to his "Commentaries" on the works of Aristotle (Hebrew and Latin translations extant) that he owed his great celebrity in the scholasticism of the Middle Ages. He had no knowledge of Greek nor of peripatetic philosophy, except through translations, but his subtle and penetrating mind identified itself to such a degree with the spirit of the philosopher of Stagira that he divined what the translators themselves did not comprehend. For a long time he was considered almost the equal of Aristotle, and was called "The Commentator". His philosophic doctrines were condemned in 1240 by the University of Paris, refuted by St. Thomas Aquinas and condemned anew by Leo X in 1513. Averroes was also considered one of the wise men of his time in medicine, on which science he wrote an important treatise, in its Latin edition (Venice, 1482, 1514) bearing the title "*Colliget*" (summary). His complete works were published in Venice in 1552. Many of his writings remain in manuscript in the library of the Escorial and elsewhere in Spain.

Renan, in "*Averroès et l'averroisme*" (1852), speaking of his philosophic doctrine, says that "the system called Averroism in the Middle Ages and the Renaissance was nothing more than a combination of the doctrines common to the Arabic peripatetics. Its author had the good fortune of the last comer, and passed as the author of doctrines which he had done nothing more than explain in a more complete manner than his predecessors".

Averroes is to be considered as the most noted representative of western Arabian philosophy. His thought is an efflorescence of the philosophical speculation of the highly developed and brilliant Moorish civilization in Spain. The enchanting country of the Alhambra was one of the most notable cultural centers of its time and the rendezvous of the students of whole medieval Europe. The cultural contacts established there were to redound to the benefit of occidental learning. Averroes was not an original philosopher, yet he merits a place in the development of European thought on account of his enormous influence. He shared with Avicenna his reverence for Aristotle. He held that Aristotle was the most perfect mind that ever appeared in the human race.

This noted Arabian is most famous on account of his interpretation of Aristotle's psychology. He explained it in the sense that the human intellect is an eternal, immaterial form, which is one for all men and is not to be identified with the minds of individual men. He taught that not only what Aristotle termed the "active intellect," but even the passive or possible intellect, is numerically one and common to all men. This unwarranted explanation of Aristotle's doctrines met with great opposition, not only in the Christian but also in the Mohammedan world, for it was tantamount to a denial of personal immortality, since the soul of individual men were not to survive death. Individual human consciousness ceases to exist, and nothing survives but the universal intelligence. His failure to distinguish between the individual human mind and the universal mind also betrays his adherence to the pantheistic tradition of the Arabian thinkers.

His writings, however, gave a powerful impetus to philosophical speculation among the Christians and notably influenced the Jewish philosophy of the Middle Ages. Perhaps the most noted exponent of Averroes's tenets in Europe was Siger of Brabant, whose importance in philosophy lies in his acceptance of Averroism in its entirety, which drew upon him the opposition of Albertus Magnus and Aquinas.

FRANCIS BACON

"The Wisest, Brightest, Meanest of Mankind"

FRANCIS BACON, afterwards Lord Verulam, Viscount St. Albans, was born in London, on January 22, 1561. His father, Sir Nicholas Bacon, was Queen Elizabeth's famous Lord Keeper of the Great Seal. His maternal grandfather, Sir Anthony Cooke, had been the learned tutor of Edward VI, and his mother was a woman of rare intellect and an ardent follower of Calvin. The boy is believed to have been assiduously taught and disciplined by her. Entering the University of Cambridge, he there came to the conclusion that philosophy, as represented by the current Cambridge rendering of Aristotle, was fallacious and in need of radical reform. He entered Parliament, and thereafter his life, more markedly than that of any other of the great figures of history, is a double one, part of it being the record of political and civic advancement, intrigue, treachery, dishonesty, disgrace, and part of it being the record of a great thinker, endeavoring to frame a theory of knowledge, and a method, or *organum*, of research by which knowledge could be rapidly and surely advanced for the benefit of existing men and of all posterity.

This "wisest, brightest, meanest of mankind" concerns us here in his capacity as a thinker. Yet, though it is impossible to trace any relation between his external and internal lives, it is necessary, very briefly, to recall the external circumstances of the man to whom we owe some of the greatest prose and most notable thinking in our language. The author of the noble essay on "Death," of the "Advancement of Learning," and of the "*Novum Organum*," a new instrument of knowledge, was also an ambitious and none too scrupulous lawyer. Having trampled upon the heads of many friends on the way, he became Lord Chancellor, but was convicted of corruption, was sentenced to be imprisoned and banished from Parliament and the Court. This was in 1621, and Bacon still had five more years to live, during which he concerned himself wholly with the worthier of the two interests of his life.

In 1620, one year before he was made viscount and his fall, Bacon — who is often wrongly called "Lord Bacon" — published his masterpiece, the "*Novum Organum*". His "Essays" are familiar to a far wider circle of readers as one of the classics of English prose literature, but the "*Novum Organum*" can now readily be obtained in English, is not long, and is remarkably easy to read, considering the nature of its subject.

Before we look more closely at his teaching, let us note, however, that Bacon did not himself make any discoveries, or put his theory to the proof; that he was not acquainted at all thoroughly with the knowledge of his time, even rejecting the stupendous discovery of Copernicus that the earth goes round the sun; that he did not even acquaint himself with Harvey's discovery of the circulation of the blood; and that in these and many other ways he laid himself open to the remark of the immortal physiologist Harvey himself, that "the Lord Chancellor writes on science like a Lord Chancellor". We may add that subsequent students have not followed Bacon's method as he laid it down, and that the really valuable parts of it had, in fact, been employed by first-hand students of nature ever since the dawn of science. But when all is said against the vast pretensions of its author, and the uncritical praise of many of his commentators, the "*Novum Organum*" remains a landmark in the history of thought, and one of the greatest masterpieces in the literature of knowledge. "We live in a time," said Bacon, "when true learning has become stifled by the arrogance of its professors, by a cloud of words and phrases, long destitute of any meaning they may ever have had, and when we need to get back to nature herself at first-hand, if we are really to learn anything about her." Beyond a doubt, Bacon was right, and his book marks the definite and effective beginning of what we call modern science.

The vice of philosophers, Bacon declared, was that they started from certain general propositions, and then proceeded to state therefrom the facts of the world, without troubling to look at the facts themselves. This method of the armchair philosopher, who evolves the details of the world out of his head with his eyes shut, may be called, said Bacon, the "anticipation of the mind", whereas the true and only useful method is "the interpretation of nature". "Man," said he, "is the servant and interpreter of nature," and directly he forgets this place and post of his, and starts to reason from his own notions, which is so easy and gratifying to his pride, he is sure to go wrong.

The mind will serve us well, if only we use it properly. But we allow it to worship the "idols of the mind", "certain idle dogmas", instead of the "ideas of the Divine mind — the real stamp and impression of created objects as they are found in nature". The reader must go to Bacon himself for his celebrated and masterly definition and exposure of these idols, which beset every one of us today and every day, exactly as they beset Bacon nearly three centuries ago, or Aristotle two thousand years before him. As Bacon said, "The human understanding resembles not a dry light, but admits a tincture of the will and passions, which generate their own system accordingly, for man always believes more readily that which he prefers." And yet, though the preferred belief may have some kind of value for the individual, may serve his life, though it be false, yet the truth is what will really serve all mankind best. "Man can only govern nature by obeying her," said Bacon, and therefore he must find out what her laws are. To this end only one means avails, and that is the systematic, patient observation of facts, and then a process of inference or induction therefrom. Hence we call Bacon the father of the inductive or scientific method.

Though Bacon made no discoveries of his own, and though he underrated the importance of wisely framed hypotheses in the search for truth, he was a genuine researcher when time availed. Early in 1626 he exposed himself unduly to cold while making an experiment on the effect of snow upon the preservation of flesh. He fell ill and died at Highgate, near London, on April 9, 1626. His bones lie in St. Michael's Church at St. Albans.

ALEXANDER BAIN
The Modern Exponent of a Material Mind

ALEXANDER BAIN, the Scotch psychologist, was born on June, 11, 1818, in Aberdeen, his father being a handloom weaver, who (to quote Bain's own words, in his "Autobiography") "was both expert and industrious", and "could earn considerably over a pound a week". The boy's home life was severe. His education began early, and he needed all the constancy

Photo Elliott & Fry

ALEXANDER BAIN

of purpose and untiring energy which he inherited from his father — a father who worked at his loom fifteen hours a day, six days a week, to cope with the needs of his large family. The boy was taught religion by his father and others, of a type and in a manner which may have largely accounted for his subsequent mental attitude.

Young Bain early distinguished himself in the university of his native town, both in what we nowadays call psychology and in the physical sciences. Soon he began to write, becoming an ally and fellow-worker of John Stuart Mill, with whom he is definitely to be classed as a member of the "associationist" school of psychologists. In 1860 Bain became professor of logic in Aberdeen, having already published his two great books, "The Senses and the Intellect" and "The Emotions and the Will", in 1855 and 1859 respectively. His psychology was based entirely on physiology, and represents the furthest limits that could be reached on the lines of the school to which he belonged. But now over half a century later it seems to belong to a mode of thought we have far outgrown.

After a long life of incessant work, Bain died on September 18, 1903, not far from his birthplace. He requested that no stone should be placed upon his grave; his books, he said, would be his monument.

JAMES MARK BALDWIN
Social Psychologist and Genetic Logician

JAMES MARK BALDWIN, son of the Hon. Cyrus Baldwin, was born in Columbia, S. C., on January 12, 1861. He was graduated from Princeton in 1884, afterward studying at the universities of Leipzig, Berlin and Tübingen. In 1886–1887 he was instructor in German and French at Princeton; from 1887 to 1889 he held the chair of philosophy at Lake Forest College, Ill.; and thereafter was successively professor of logic and metaphysics at the University of Toronto, Stuart professor of psychology at Princeton (1893–1903), and professor of philosophy and psychology at Johns Hopkins University (1903–1909). In 1909 he became honorary professor at the National University of Mexico.

Dr. Baldwin has been the recipient of many honorary degrees from universities. He is an officer or member of numerous scientific congresses and societies, was president of the American Psychological Association (1897–98), and succeeded William James as foreign correspondent and member of the Institute of France (1909). He founded psychological laboratories at the University of Toronto and at Princeton, also, and with J. McK. Cattell, in 1884

established the *Psychological Review*, of which he was editor until 1909. He was also editor-in-chief of the "Dictionary of Philosophy and Psychology" (3 vols., 1901–1905) and contributed many of its leading articles. In 1915–1916 he was Herbert Spencer lecturer at Oxford University, and at the same time Harvard lecturer to the French Provincial Universities. In 1918 he became lecturer at the École des hautes études in Paris, and the year following he was made professor there. He received the cross of the Legion of Honor in 1917.

Besides many contributions to learned journals and encyclopedias Dr. Baldwin is author of the following works, many of which have passed through several editions and been translated into one or more foreign languages: "German Psychology of Today" (trans. 1886), "Handbook of Psychology" (2 vols., 1889–1891), "Elements of Psychology" (1893), "Mental Development in the Child and Race" (1895), "Social and Ethical Interpretations in Mental Development" (1897), "The Story of the Mind" (1898), "Fragments in Philosophy and Science" and "Development and Evolution" (1902), "Thought and Things, or Genetic Logic" (3 vols., 1906–1911), "Darwin and the Humanities" (1909), "The Individual and Society" (1910), "History of Psychology" (912), "Genetic Theory of Reality" and "France and the War" (1915), "American Neutrality" (1916), and "The Super State" (1916).

The rapid advances achieved during the nineteenth century in the various special sciences dealing with mankind, such as anthropology and ethnology, as well as biology, history and especially psychology, both demand and prepare the way for a general reconsideration of the nature and significance of human life as manifested in concrete social experience. Moreover, previous attempts to interpret the nature of this experience, which, according to Baldwin, is the essential substance of reality itself, have failed, not only because of insufficient data upon which to base any relevant conclusions, but also, he holds, because the wrong method was employed in utilizing such data as was at hand. Neither bare historical records nor logical abstractions — the products of two of the favorite methods previously considered — furnished the proper means by which to arrive at a satisfactory interpretation of the ultimate nature of things. Rather, for this interpretation, we must turn, Baldwin maintains, to a social psychology, wherein is to be set down an account of the actual mental progress of the human species. In other words, Baldwin's aim is to express in psychological categories, first,

PROFESSOR J. MARK BALDWIN

the nature and meaning of society and the individual's relation to it, and, secondly, the meaning of reality in general, conceived of as issuing legitimately from this same mental movement.

More particularly, Baldwin points out, his problem may be formulated as an attempt to restate, from a genetic and evolutionary point of view, Comte's conception of the "stages" of thought, in such a form as to include the essence of Comte's own theory and certain additional features making for a completeness lacking in the original.

This advance beyond the work of Professor Baldwin's predecessors becomes possible mainly because of the results of the Darwinian theory of evolution in biology — the theory which "involves defining a thing in terms of what it does and becomes, and of what it arose from". So, by analogy, the "genetic" method as described and employed by Baldwin "inquires on to the psychological development of the human individual in the earlier stages of his growth, for light upon his social nature and also upon the social organism in which he bears a part".

As the outcome of the application of this method, Baldwin finds that there are three fundamental stages in the progressive movement of experienced reality. The later stages, however, are not to be thought of as issuing mechanically from the former, according to the views of Herbert Spencer, but rather as manifesting a real advance, an evolutionary progression on the part of nature to continuously higher modes of existence. Actually new things — novelties — are daily achieved in life, mind and society; results which we cannot interpret in terms of mere composition of the elements involved. The postulation of an immanent principle of change, issuing in modes of reality which are progressively more and more significant for the demands of intelligence and life thus makes possible an interpretation of the world in terms of an organization of which progressive, self-integrating social experience is the type.

The first stage is one of "immediacy"; the primitive member of society, or the child, genetic investigation shows, does not make any distinction between the "inner" and the "outer", between the self and the world. Its immediate experience is, as James said, a "buzzing confusion", of which the chief characteristic is mere sentiency, not ascribed as to origin, by some higher mental function to develop later, either to its own body or to external objects. Only after a certain further period of experience does the individual learn to distinguish things and persons from himself and that only because he is a member of a society whose intellectual and moral motives form the basis of presupposition of his own. Thus the individual, Baldwin is fond of emphasizing, is the outcome of his social environment; through the power of imitation which even the most primitive being inherits from his ancestors, he gradually learns to treat objects in the external world as foreign to himself and in a measure amenable to his purposes. For example, he learns to imitate another member of his group in the use of crude instruments. At the same time desires peculiar to himself arise, which conflict with those of his comrades; hence he comes to distinguish more and more clearly between other persons and himself.

During the process of development the second great stage of genetic evolution is coming gradually into existence. Once the fundamental dualisms between inner and outer are set up, others arise in quick succession, until the list becomes comparable to that of our own times. This is the state of "mediation", of "selective thinking", in which the members of society learn to employ thought and will to overcome the problems furnished by the natural environment and by the sphere of moral action, respectively. As a result of the opposition of the external world to social or personal motives, there springs into existence the love of truth, which signifies nothing more or less than ability to subjugate nature to man's purposes. And within the social environment proper we learn to distinguish good from evil, that being good which furthers the well-being of the several members of society and the expense of none. Here, then, is the root of such distinctions as that between mind and body, subject and object, freedom and necessity, actual and ideal. Here arise also those various theories about the nature of reality characteristic of emphasis upon one or the other side of some particular dualism. On the one hand we have pragmatism, positivism, intuitionism, corresponding to extreme emphasis upon the individual in contrast with society; and on the other hand, postulates of absolute thought or will, corresponding to emphasis upon one or the other abstract social motive — truth or goodness.

But there is a further stage implied in the two foregoing derived from them, and yet superseding them. For genetic research shows that man feels the need ultimately of overcoming these dualisms, of in some sort achieving a "higher immediacy", analogous to that of the first stage, but richer, more complete and capable of satisfying all the demands of his nature. And by means of the "creative imagination" the individual, the outgrowth of society, is enabled to repay his debt of dependence upon society by producing works of art embodying a final synthesis of the dualisms of the previous stage. Unlike religion, which involved a dualism between the ideal and the actual, the concrete work of art is at once the ideal and its realization. In contemplating an artistic production, as in creating it, the individual naturally merges himself with it to the limit of his imaginative ability, until finally he comes to recognize this "all-comprehensive and completely full experience" as the very quintessence of the ultimately real. The æsthetic, the beautiful, it is explained in detail in Baldwin's doctrine of "Pancalism", is thus a self-constituted whole, a unity of all partial aspects of things, and one which accurately embodies the ultimate meaning and goal of human experience.

JEREMY BENTHAM

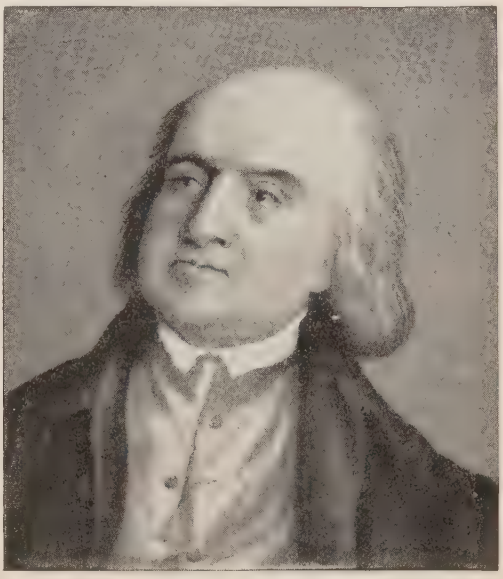
The Hermit-Prophet and Philosopher of Radicalism

JEREMY BENTHAM was born in Houndsditch, London, on February 15, 1748, the son of a well-to-do attorney. The precocity of the child led the father to invent eccentric methods of education; he was continually exhibited as a prodigy. He began the study of Latin at three, went up to Oxford at twelve, and was entered at Lincoln's Inn at sixteen. His father's desire to see him a judge was prevented by the youth's failure in the courts.

Turning from the practice to the theory of law, Bentham became the greatest critic of legislation and government of his day. "A Fragment on Government" (1776), an attack on views expressed in Blackstone's "Commentaries", contains the germs of most of his later books. Its success was instantaneous.

It must be acknowledged that he owed no small amount of his fame to the brilliant French translations of his works by M. Dumont. Bentham only became tolerable and intelligible, according to Sydney Smith, after he had been washed, trimmed, shaved and forced into clean linen. Certainly it was in France that he first attained any considerable popularity.

He was the philosopher of Radicalism; he urged many of the reforms that have either come or are coming, but he failed to see that progress depends upon the education of the popular mind. Macaulay never ceased to do honor to Bentham as the father of Jurisprudence, but he offered



JEREMY BENTHAM

the most brilliant, the most contemptuous, and the most shattering opposition to the upholders of the doctrine of utility which pervaded most of Bentham's political writings. "We apprehend," he wrote, "that many of them are persons who, having read little or nothing, are delighted to be rescued from the sense of their own inferiority by some teacher who assures them that the studies which they have neglected are of no value, puts five or six phrases into their mouths, lends them an odd number of the *Westminster Review*, and in a month transforms them into philosophers." He spoke of them as "smatterers whose attainments just suffice to elevate them from

the insignificance of dunces to the dignity of bores, and to spread dismay among their pious aunts and grandmothers."

Macaulay truly pointed out that Bentham's principle of "the greatest happiness of the greatest number" — a phrase which Bentham had adopted and made famous — was as old as the precepts of Christ, but that with Christ the injunction of the Golden Rule was accompanied by a sanction of immense force. "He should reflect that the whole vast world of morals cannot be moved unless the mover can obtain some stand for his engines beyond it. He acts as Archimedes would have done if he had attempted to move the earth by a lever fixed on the earth. The action and reaction neutralize each other. . . . Mr. Bentham can only tell us to do something which we have always been doing, and should still have continued to do, if we had never heard of the 'greatest happiness principle' — or else to do something which we have no conceivable motive for doing, and therefore shall not do." But, in spite of all this fine criticism, Bentham did undoubtedly give a fresh energy to political economy.

He dressed as a Quaker, lived like a hermit, and, with the exception of music, knew nothing of the arts. He occupied his father's old house in Westminster, and, though a delightful host to guests of his own invitation, kept his door shut against all intruders, even the most famous. Madame de Staël once sought an audience, and received the message that Mr. Bentham certainly had nothing to say to her, and could not see the necessity of an interview for anything she could have to say to him. Mr. Edgeworth, the father of Maria, with his usual pomposity, sent this message into him by the servant: "Tell Mr. Bentham that Mr. Richard Lovell Edgeworth desires to see him." "Tell Mr. Richard Lovell Edgeworth," came the answer, "that Mr. Bentham does not desire to see *him*."

Jeremy Bentham lived to be eighty-four and died on June 6, 1832. He left his body for dissection, and his skeleton stands in London to this day, dressed in his old clothes, at University College.

HENRI BERGSON

Whose Philosophy Relies on Intuition

HENRI BERGSON was born in Paris, of Jewish ancestry, October 18, 1859. At the close of his academic education, in 1889, he published as a thesis for the Doctorate the "*Essai sur les données immédiates de la conscience.*" This book, which was translated into English in 1910 under the title "Time and Free-Will," already presents the main outline of his system. His other two principal works "*Matière et Mémoire*" (1896), and "*L'Evolution Créatrice*" (1907), were translated into English in 1911. The latter work has passed through twenty-four French editions. Translations of his other works appeared as follows: "Introduction to Metaphysics," in 1912; "Laughter," in 1911; and "Mind-Energy," in 1920. This last work, which is a series of essays, shows the great interest Bergson takes in the phenomena of abnormal psychology and psychical research.

Since 1900 Bergson has been professor of philosophy at the Collège de France. In 1913, he lectured at Columbia University in New York, and he has also lectured extensively in England. He was president of the Society for Psychical Research in 1913, and was made a member of the French Academy the following year. In 1915 he became president of the *Académie des Sciences Morales et Politiques*, and numerous other honors and degrees have been conferred upon him.

At the time when Bergson began to occupy himself with philosophical problems much interest was being taken in the biological sciences, and especially in the theory of evolution. It was therefore natural that the work of Herbert Spencer should attract his attention. Now Spencer, it will be remembered, described the evolutionary process as consisting essentially in the redistribution of matter and energy; in a progressive adjustment of factors and forces which are taken as given, ready-made, perhaps contained in the primitive nebula from which the movement is supposed to set out. This was for Spencer not merely a good scientific hypothesis,

but a universal formula, to be applied to the actual world-process. In such a world mechanical principles of explanation rule supreme; that is to say, everything is theoretically determined beforehand both as to the time of its appearance and in all its relations to other parts of the huge machine.

Bergson saw that no other conclusion is possible so long as only the methods and principles of the physical sciences are employed to determine the nature of the evolutionary process. It is the aim of the physicist, for example, to construct a static view of things, artificially fixed outside each other in space, and held together only by the principle of causality, which is itself merely an expression of quantitative relationships. By analogy we break up our minds into "states of consciousness", and we even proceed to analyze these states into their smaller component parts such as discrete sensations.

Moreover, the classical historical systems of philosophy, according to Bergson, quite generally accepted the methods and conclusions of the various sciences as ultimately valid and true for the fields to which they applied. If it pleased the physicist, for example, to analyze color into "waves" of various lengths and frequencies, the philosopher was disposed to accept the results of his analysis as a real explanation of the nature of color. We are the more inclined to accept these abstractions because in our ordinary, everyday life it is convenient to have things thus formally schematized and labeled, since they can in this way the more easily be made to serve our practical purposes. And Bergson does not deny the value of these applications of scientific principles to our immediate needs. Indeed, he was at first disposed to accept the mechanical account of the world as final. But gradually he came to realize that from such a point of view "nothing ever really happens", nothing new ever comes into existence; it is a static world in which "creative evolution" has no place. Either life is a chimera or it will find a way to escape from the limitations imposed upon it by the notion of an inert matter.

Moreover, it is the function of the philosopher, Bergson maintains, to keep clearly in view and to explain the real nature of our concrete experience. Focusing his attention too exclusively upon the attempt to extend knowledge and to construct theoretical systems based upon abstract principles, the philosopher has permitted the scientist to lead him astray. When we examine the matter carefully, Bergson insists we find that knowledge itself is only a product of the intellect, of the abstract, reflective understanding. The results obtained in science and in traditional philosophical speculation, he argues, are sufficient proof of this indictment. Now abstraction can only breed further abstraction, while reality is something concrete. No wonder, then, that we have made so little progress toward discovering the nature of concrete reality, and so little success in attaining a satisfactory solution of the problem of freedom. Thinkers of the past succeeded, it is true, in attaining a conception of evolution, but they failed to grasp the real significance of the notion. Evolutionists vainly endeavored to explain the meaning of life, by attempting to analyze it into more ultimate parts according to the principles of mechanical science. Such a method was foredoomed to failure simply because life is too concrete a unity to permit of its being broken up into any more simple factors. We must either find a means of grasping it in its wholeness, as directly experienced, or admit that its nature is an insoluble mystery. Suppose, now, that we depose theoretical knowledge from its traditional position as the ground and goal of our philosophizing. Since it has proven itself inadequate to solve the problem placed before it, Bergson contends that we are at liberty to reject its claim to supremacy in favor of the more ultimate principle which life may justly claim to be. The problem then remains of how we are to ascertain the character of this vital force, this "*élan vital*", as Bergson calls it. Fortunately, we possess a power of mind commonly known as "intuition", a power which is so akin to life that it at once yields up the secret to those who give it rein.

A moment's reflection will reveal the reason for this. Life is a process, a spontaneous growth, a development in time. And we are immediately aware of the passage of time or "pure duration." It is inescapable, of our very essence. Try to seize it with the intellect and it is gone, but intuition follows it, or rather keeps pace with it and conforms accurately to its every manifestation. As a rude figure of comparison, we may think of the intellect as a photographic plate registering moving phenomena in cross-section, while the intuition may be compared to the cinematographic film of the same phenomena.

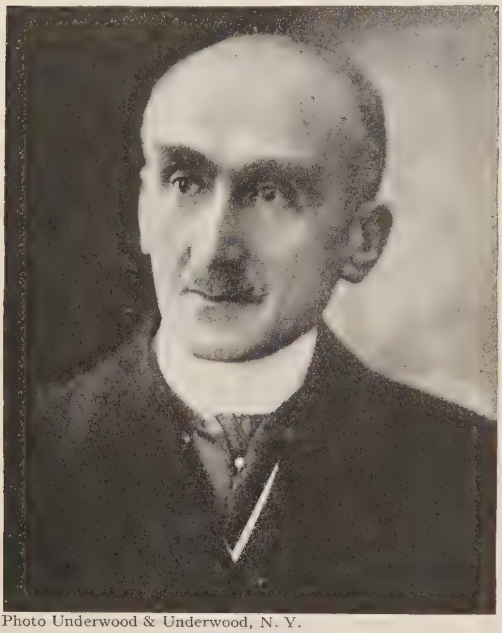


Photo Underwood & Underwood, N. Y.

HENRI BERGSON

In other words, the concrete movement of life and history is just what science fails adequately to explain, and hence philosophy, if it is to discover the real significance of things, should adopt intuition instead of the abstract understanding as its guide.

And the problem of freedom, so long insoluble, now solves itself. By hypothesis the law of causality applies to the entire subject-matter of science. But life, eluding all attempts of science to analyze it into discrete parts, mechanically determining each other, succeeds in maintaining its character whole and entire, as the origin and source of all new creations. And precisely in this freedom will be found to consist. It is not a function of an abstract "will", located somewhere outside a static world of science, but the very essence of the real world of continuous change in which we live.

Bergson never tires of emphasizing this contrast, variously expressed as that between intuition and intellect, philosophy and science, freedom and determination. As an example of this we may consider his solution of the problem of the relation of mind and body. Since for the traditional view of the world all natural phenomena are absolutely determined, according to the laws of science, it is possible under such circumstances to conceive of freedom of the will only if mind be entirely isolated from body, set apart from its natural surroundings in a mythical region of private "ends" of its own. But since for Bergson freedom is of the very essence of the evolutionary process, he is able to conceive of mind in terms of life itself. Mind is just the expression of life at a certain level, while body is the complementary manifestation of the spiritual in the material. Mind and body are not dissociated elements, therefore, as is commonly supposed, but are merely different aspects of the selfsame vital principle.

By means of the revealing power of the intuition, then, we acquire real insights into the character of the creative activity called life. Manifesting itself in all the various forms of the evolutionary process, it everywhere employs matter as its vehicle, and asserts its freedom in ever new, unique productions. In Bergson's own words: "Reality is a perpetual growth, a creation pursued without end. Our will already performs this miracle. Every human work in which there is invention, every voluntary act in which there is freedom, every movement of an organism that manifests spontaneity, brings something new into the world."

Evidently such notions as these have a direct application to the problems of psychic phenomena and immortality, and it is to be hoped that Bergson will some day find opportunity to give his solution of these problems.

CHOICE AND CARE OF FABRICS

Tests That Show Whether Materials
Are What They Are Claimed To Be

HOW TO RECOGNIZE FIBERS, QUALITY AND VALUE

A GIVEN piece of material may be sold as cotton, linen, wool or silk, respectively, or a mixture of these fibers, but every purchaser as well as the salesman should be able to confirm the statement on the label. Not only is a qualitative estimate of importance to avoid deception, to judge of the probable wearing qualities of the material, to estimate its monetary value, and to know what treatment it can safely undergo in the cleansing processes, but a rough quantitative estimate will be of use particularly in valuing it; and an examination for possible flaws or defects in weaving, for short fibers in the yarn, and for the presence of dressings which will cover up such flaws and, in the case of silks, for "weighting" which will affect the wearing qualities, will be of the greatest value. Unfortunately, many of the trade names under which materials are sold are misleading. Flannelette is not a modified flannel, but is cotton made to have somewhat the appearance of flannel. Artificial silk is not silk at all, but is made from cellulose (woody fiber or cotton) which is so treated that it has a silky sheen. Cotton fabric is sometimes treated to make it look like linen. Cheaper fibers may be used with better ones, yet hidden by them, and the price is usually in no way a criterion for quality.

The question arises as to whether such treatment as making one fiber look like another, or of mixing a cheaper fiber with a more expensive one, or of "re-working" wool, is desirable. It depends. Cotton mixed with wool makes the material shrink less in washing, therefore may be desirable in some fabrics, though such a mixed fabric will not give the same warmth as a pure wool one. Cotton mixed with wool makes a cheaper material than the all-wool fabric could possibly be, and yet the mixture is warmer than cotton alone. It also brings the price of a "woolly" material within reach of the poorer members of the community. The re-working of wool makes the supply of wool goods greater, and with care and discrimination in preparation, and by mixing with it a certain proportion of virgin wool, the wearing quality of the material will approach very nearly that of the virgin wool, but its price should be less. It must be remembered that if all the wool produced in the world were evenly distributed among the inhabitants outside the tropical regions, each individual would get only about fourteen ounces each year and the price of pure wool would be greater than that of silk. Silk is a very expensive fiber, and unless imitations were made, and unless silk other than that produced by the cultivated silkworm were used, a silk garment would be so expensive that it would have to be worn, as it was a century ago, for a much longer period than is compatible with the swiftly changing fashions of today.

The use of substitutes and imitations is therefore legitimate for certain purposes and no objection can be raised, on the whole, if the fabrics are described correctly and priced accordingly. When fabrics are standardized as carefully as are the food products on the market today, there will not be the same need for the purchaser to know how to recognize the fibers as there now is, or the same need to look for flaws, dressings and weightings.

The fibers commonly used for the manufacture of ordinary fabrics

The fibers commonly used for the manufacture of ordinary fabrics today can be divided into two classes: (*a*) fibers of animal origin (wool and silk), and (*b*) fibers of vegetable origin (cotton, linen and artificial silk). Fibers of mineral origin are so rarely used that they need not enter into our consideration. The characteristic appearance and feel of these five fibers is distinct, and a knowledge of them can be acquired by handling samples of the pure threads and materials much more easily and perfectly than from any verbal description. Pieces of standard materials should be studied for appearance, feel, weight, finish, and comparative costs,

Ash from unweighted (left) and weighted (right) silk when allowed to burn in air.

so that the fabric under consideration can be compared with these. A piece of the yarn from the warp and the weft of the material should be separated and untwisted. This will show that the yarn is made by twisting together a number of fibers which vary in length according to their nature. The average length of cotton fibers is from three-quarters of an inch to nearly two inches. If unusually short fibers are twisted together to form the yarn, the tensile strength will be reduced and fabrics made with such yarn will probably be damaged very quickly by laundering and use. The better quality materials are made from the longer fibers, the shorter ones having been removed in the combing and carding processes. Linen fibers are much longer and consequently when spun together, make a stronger yarn than cotton. They have also a much greater luster. Wool fibers vary from two to twenty inches in length, the short duller staples being used for soft, loosely twisted, "woolen" materials, while the longer and more lustrous ones are used for closely twisted yarns to make serges, covert cloths, "worsted" suitings, etc. Silk fibers are very long, glossy, and elastic. When spun by the silkworm, the length of the fiber may be anything up to fifteen hundred yards; and not only are these great lengths twisted together to make a thread, but the short, broken pieces from the outside and inside of the cocoon and short lengths from spoiled cocoons are also twisted or spun together to make a yarn which, although pure silk, will not have the same strength as the yarn from the long fibers. Silk from the "wild" or uncultivated silkworm is not so fine, white or lustrous as that from the cultivated worms. Artificial silk fibers are also of great length, but are not so elastic or strong as the real silk fibers, and they possess a more metallic luster.

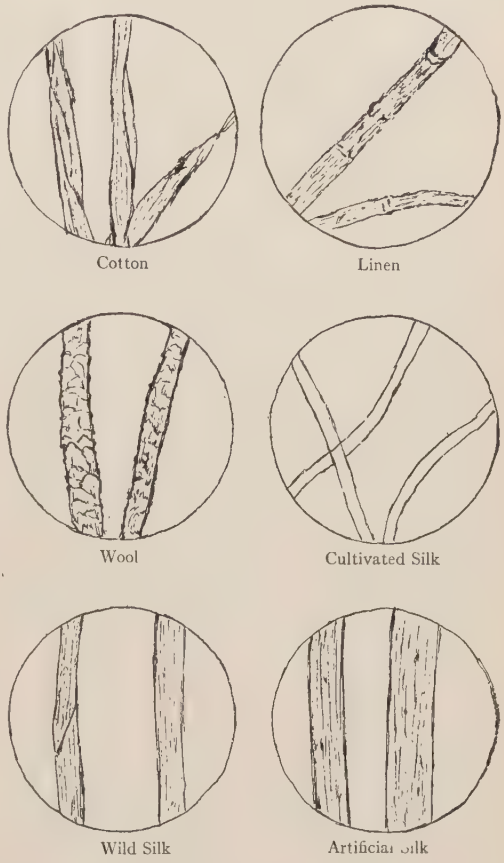
Two kinds of fibers may be spun together, or woven together, and the examination of the threads from the warp and the weft of the material will indicate whether one or more kinds of fibers have been used in the spinning and weaving.

Not only can the fibers be identified by their appearance and feel, as indicated above, but they burn with characteristic differences. The animal fibers burn slowly — wool much slower than silk and with a more disagreeable odor. Wool leaves a crisp black residue; silk, a very little black ash, unless weighted with metal compounds, when a white or gray residue retaining the shape of the original material is left (see illustration). The vegetable fibers burn quickly (artificial silk being the most rapid) and with practically no odor, except in the case of artificial silk, and leave a very little white ash. In a mixed fabric, the presence of the odor of burning wool does not, however, mean the absence of cotton or linen, although the absence of smell must necessarily mean the absence of wool or silk.

To confirm these tests, or if it is suspected that the material is a mixture, boil for a few minutes in a strong solution of lye (caustic soda). The solution may be made by dissolving one tablespoonful of lye in half a pint of water. Cotton and linen are not destroyed, though they may be made tender, but linen (unless fully bleached) will become yellow in tone; wool will dissolve very rapidly and silk less rapidly, while artificial silk will be gelatinized in a few seconds without actually dissolving. The rate at which the silk dissolves also distinguishes wild from cultivated silk, wild dissolving only when boiled for from thirty minutes to an hour, while the cultivated silk dissolves in from five to ten minutes.

Another means of identifying fibers is to warm them in a solution of picric acid, which can be obtained as a saturated solution at any drug store. Wool and silk will be permanently colored, while cotton, linen, and artificial silk will be stained only and the yellow color will wash out. The use of muriatic (that is, hydrochloric) acid also readily identifies cultivated silk, which will dissolve in this acid in about one minute, unless it is weighted with tin compounds — when the solution will be slow, but will be hastened by heating. Artificial silk, under similar conditions, will very quickly be rotted.

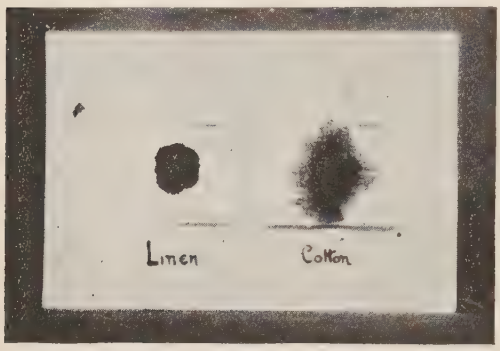
If one has a microscope, this is the quickest and surest method of identifying fibers, for they have very characteristic appearances, as illustrated on this page. In fact, the microscope is the only *sure* method of differentiating linen and cotton. Both are cellulose materials and react similarly with chemicals, particularly if bleached, though there are some slight differences in other ways which can be looked for. If the linen is unbleached or only partly bleached, it will become decidedly yellow in the lye solution. If, however, it is fully bleached, there is little or no difference between it and cotton. If a drop of water or ink be placed on pure linen or pure cotton, there is a difference in the behavior of the drop, dependent on the material; the liquid seems to stand on the surface of the cotton for a few seconds and then spreads rather far in all directions, while on the linen it sinks in at once and forms a more concentrated and compact stain (see next page). On a mixed cotton and linen fabric this test fails, as does also the oil test. Oil dropped on pure linen, however, makes a translucent spot while on pure cotton it makes an opaque spot.



TEXTILE FIBERS: MICROSCOPIC APPEARANCE

The proportions in which wool and cotton are mixed, and whether they are spun or woven together in any fabric, and the pattern of the weave, is indicated by boiling the fabric in lye, when the wool will be destroyed and leave the cotton (see page 1905, 1–4). If the mixture is silk and cotton, or silk and wool, the silk can be removed by treating with muriatic acid for a few moments and then rinsing (see page 1905, 5 and 6).

In choosing and identifying fabrics, it is well to know what possible deceptions and sophistications may be practiced. Cotton may be made to look like linen by using a rather unevenly spun thread, by using a "linen" weave, and by beetling and calendering; and to have a silk finish by mercerizing. A so-called "linen" may be a mixture of linen and cotton. A poor quality cloth may have a heavy dressing which will disappear in the first laundering and leave a thin, sleazy material with possibly several flaws in it, such as loose or broken threads, or other injuries due to carelessness or haste in manufacture. The fabric will probably wear very quickly at such places when laundered. Silk is frequently woven with cotton one way and sold as "silk." Wild silk is sometimes



An ink-spot on linen and cotton fabrics.

used with cultivated silk and sold at the price of cultivated silk. Artificial silk is sold as "silk". Cultivated silk is sometimes so heavily weighted with tin compounds to give it stiffness and rustle that even without use it becomes full of holes almost at once. This is possibly owing to the crystallization of the tin and the consequent cutting of the fibers. Cotton is "plated" or "surfaced" with silk. The reason for the high cost of genuine and durable goods becomes apparent when one studies the subject.

While no definite statement can be made as to the length of time that any fabric should wear, every one knows that its useful period of service is affected by three factors: (1) its quality at the time of purchase, (2) its use, (3) its treatment in the laundry.

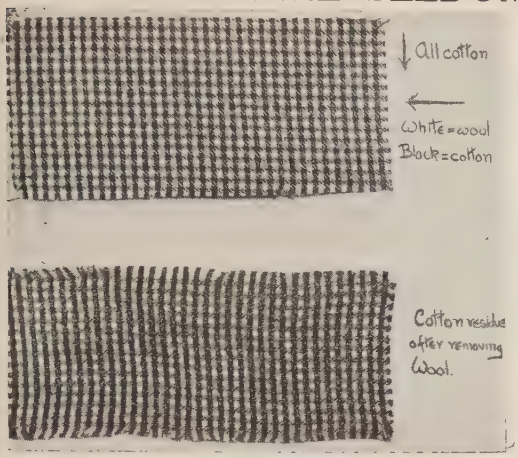
(1) For this manufacturer or dealer is, of course, responsible in the first place, but we have tried to show that the buyer should be in possession of such knowledge as will enable her to avoid deception as to the quality and composition of the cloth; to be able to detect flaws in the weaving which will cause the material to become full of holes with wearing and washing; and to be able to judge of the probable wearing qualities of the material.

(2) In the matter of use, the responsibility is purely the user's.

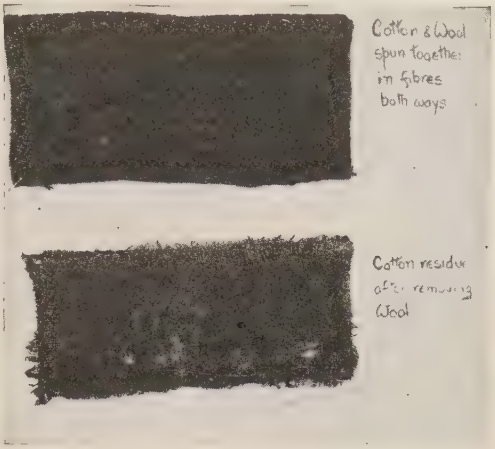
(3) We have, in the chapter on cleaning processes, shown that the proper treatment for the removal of stains is essential for the normal life of a fabric, and that the immoderate use of washing soda and other alkalies, and particularly the indiscriminate use of bleaching agents, is a large factor in the destruction and undesirable appearance of materials. It should be understood that every process in the laundry will have some effect on the fabric, but we believe that with careful and correct mechanical treatment, by the careful, correct use of stain removers and bleaching agents, and by using pure soap together with soda in the proper amount, or by replacing soda with borax or ammonia in the case of wool and silk, the destructive effects can be reduced to a minimum and the material will last a normal length of time, dependent on the initial quality and use as well as on its laundering. It will be convenient at this stage to summarize the various rules for washing clothes.

White cotton and linen goods should be soaked for some hours previous to washing, as this certainly loosens much of the dirt, removes some stains and softens starch. Cold or warm water must be used; hot water is to be avoided, as it will harden any coagulable matter present. If the water is hard, it should be softened by having one tablespoonful of washing soda dissolved in approximately ten gallons before the clothes are put in. The solid soda should on no account be thrown in on top of the clothes, as it will then form a concentrated solution in spots. A little soap may be rubbed on very soiled parts of clothing, such as cuffs, collars, etc

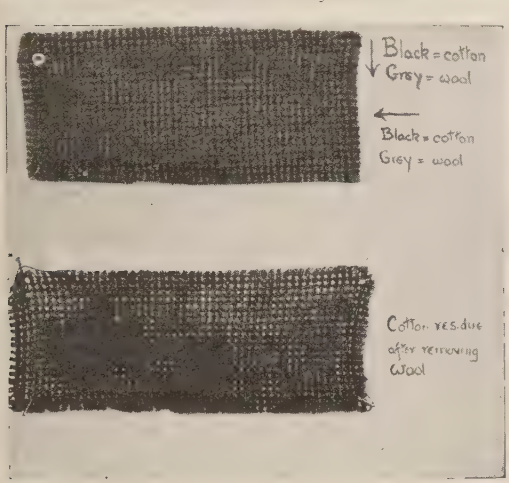
THINGS ARE SELDOM WHAT THEY SEEM



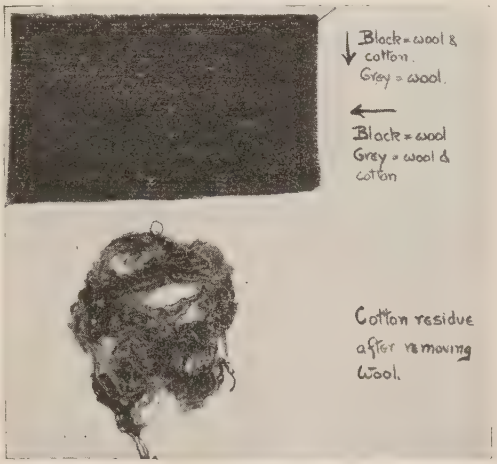
1. Cotton residue after removing wool shows that the white threads in one direction only were wool.



2. In this case the cotton and wool were spun together in fibers both ways.

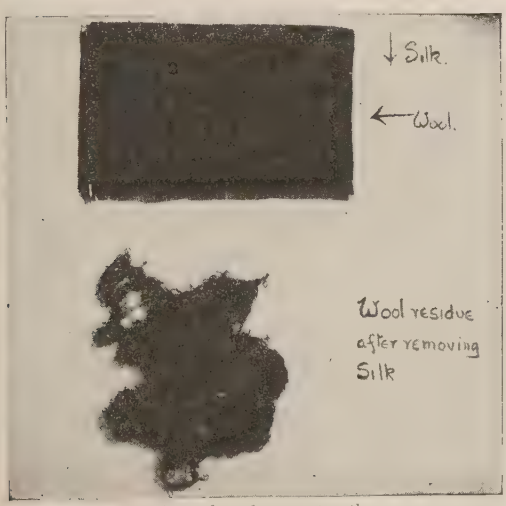


3. Here the gray threads in both directions were wool while the black were cotton.



4. Some threads in both directions wool and cotton spun together, the remainder wool.

COTTON AND WOOL MIXTURES



5. Silk and wool woven together.

6. Cotton and silk woven together.

SILK AND WOOL AND SILK AND COTTON MIXTURES

After soaking, the clothes should have the dirty water wrung out of them, and then be transferred to soapy water which has been prepared, after it has been suitably softened by adding either soap jelly (made by dissolving shredded, hard soap in hot water) or soap chips, and beating it till a nice, but not too heavy lather is formed. They should be kneaded and squeezed in this until they are clean; a second bath may be required. In the washing-machine they should be treated for ten to twenty minutes as their condition requires. Gentle rubbing by the hands will help to remove dirt from the very soiled parts. Rubbing on a washboard is very destructive and should be resorted to only when absolutely necessary for the coarse fabrics.

When the clothes are thoroughly clean, they should be rinsed in clean water to remove the dirty, soapy water before being boiled, as otherwise it will be "boiled in" and the clothes will not be a good color. Neither will they be if they are not clean before they are boiled. Boiling helps to bleach clean clothes but its main purpose is to sterilize them, so that even when a washing-machine is used the clothes should be boiled occasionally. The boiler is prepared by softening the boiling water carefully and adding a little soap, but not sufficient to make a lather. It should be somewhat below boiling-point when the clothes are put in and afterwards gradually raised in temperature and allowed to boil ten to twenty minutes. The clothes should then be removed, allowed to drain a few seconds, and rinsed first in hot, then in cooler water. The use of hot water for the first rinse prevents the formation on the clothes of insoluble acid soaps which are difficult to remove.

Thorough rinsing is absolutely essential if clothes are to be white. Any soap left in them causes slight discoloration on drying. Blueing is seldom necessary if clothes have been treated in this way with a pure non-resinous soap, and if the use of "bleach" and excess soda or other alkalies has been avoided. The need becomes even less if clothes are dried in the open air and sunshine, for this helps to bleach them.

In the washing of woolens the nature and structure of the wool fiber necessitates a treatment slightly different from that to which white cottons and linens can be subjected. Reference to the fiber figure will remind the reader that that of wool is long and cylindrical, with flattened horny scales overlapping each other on the surface. When subjected to the action of *hot* water, particularly in the presence of soap or free alkali, the fibers swell, and if there is much movement and rubbing or pounding the scales interlock and the material will become felted together. As this is precisely what has to be avoided, and in order that the softness and elasticity of the material may be retained, hot water and much pounding and rubbing must be eliminated. The material must be gently kneaded and squeezed in the soapy water. Woolen clothes are best washed in *lukewarm* water which has been softened with the proper amount of borax (or, failing that, ammonia) and to which has been added some good pure soap (jelly or chips) in quantity sufficient to make a lather about one inch thick on the surface of the bath before putting in the articles. The soap should be entirely dissolved before the clothes are put in the bath. When clean (that is, after perhaps two or three soap baths), all soap must be thoroughly rinsed out and the articles should be dried in a cool atmosphere. A drying chamber is usually too warm. Woolen garments which are likely to pull out of shape should be laid on a table or on a sheet on the grass and patted into shape before being left to dry.

Blankets which are very soiled, and other wool articles, can be soaked for a short time before washing. The prolonged action of cool water does not cause felting and shrinking.

Silks which are washable should be treated in precisely the same way as wool. The use of alkali (except a little borax or ammonia) or adulterated soap is detrimental. Rubbing and twisting will pull the threads out of place, so silk should be treated very gently and the water squeezed out by hand or by a rubber wringer. A little blue may be added to the last rinsing water for white silk.

SECRET OF THE SUN'S POWER

Whence Does the Sun Derive the Energy
So Prodigally Dispersed Through Space?

NO FINAL ANSWER GIVEN BY SCIENCE

HAVING some idea of the great measurements of the sun, and having studied in outline the sun's significance for the earth, we have to plunge — for mind can go where body cannot follow — into the sun's depths, in the attempt to discover the nature and constitution whereby this mighty globe is enabled to do its radiant deeds.

The older way of stating the first problem that confronts us would be to ask the source of the sun's heat. But in these days we can no longer restrict our inquiry in this manner, for we have the idea of energy, we have begun to "think electrically", and we know that this problem of the sun's heat is simply one part of the real question. The sun produces radiant energy — which we call heat, light, etc. — in quantities that are certainly huge. What is their source? We accept the doctrine of the conservation of energy, and we know that there must be a source, and that one of two things is sure: either the sun is only reflecting, so to speak, energy of some kind which it is constantly receiving from without, or else the sun is spending its capital of energy, and must some day — only that "day" will be sunless night — become bankrupt. The first point to decide is the magnitude of the facts which we must somehow explain. How much energy does the sun produce?

Here is a question which can, to some extent, be much more satisfactorily answered than the older one — how hot is the sun? For we can definitely measure the energy of some of the sun's radiations, especially those which we call heat; and though we shall always fail, in our experiments, to do justice to the sun, since so much of its energy never reaches our instruments, and since so much more cannot be recorded by them, yet we can positively state that the sun's energy cannot amount to less than a certain figure.

Some idea of it may be obtained by an illustration, the mere numbers being quite useless when they are so huge. Starting with a consideration of the sun's heat alone which, as we have said, is only a part of the sun's entire energy, we may recall the celebrated estimate made by Sir John Herschel. That great son of a greater father reckoned that if a mighty glacier, a cylinder of ice forty-five miles in diameter, were to rush into the sun *at the speed of light*, so that not far short of two hundred thousand miles of this colossal cylinder of ice were shot into the sun in every second of time, the sun's heat which is continuously escaping from its surface would suffice to melt it as it came. Considering, again, only the heat of the sun, we may reckon that every square foot of its surface radiates into space as much heat in twenty-four hours as would be produced by the burning of sixteen tons of coal; and a few acres of the sun's surface would comfortably replace all the energy-converting machinery — steam and oil and what not — on our planet.

Another way of trying to express what our minds really cannot fully appreciate is to think of the heat and light which we feel, and the consequences of which upon our planet we see, and then to ask ourselves how much of the sun's energy comes our way at all. The result is startling.

The earth is ninety-three millions of miles away from the center of energy which is pouring its resources into space *equally in all directions*. The heat and light which strike the surface of our bodies with such intensity that we cannot endure their continued application without discomfort, or even the total heat and light which strike the entire surface of our earth — a mere pellet of matter placed at this tremendous distance from the sun — these are so minute a fraction of the energy the sun is radiating everywhere that figures can but poorly express its minuteness. The whole earth receives less than one two-billionth of the sun's output of energy, and the whole solar system retains only about one one-hundred-millionth of it. All the rest flies onwards into infinite space. We know that it cannot be destroyed. What becomes of it no man has yet begun to conceive.

What, then, is the source of this colossal and apparently inexhaustible expenditure of power? Astronomy asks no more important question, and that for two distinct reasons, of which the first will suffice for the present.

How we live by a trifling fraction of the bounty of the sun

We live by the bounty of the sun — by an infinitesimal fraction of his bounty, the greater part even of that trifling fraction being wasted by us. But the expenditure goes on; and even if we wisely employed all the energy that falls upon the earth, all the rest flies past in and away from it in all directions, forever useless to us. How long can this unparalleled extravagance last? We need only the merest crumbs, but if the spendthrift goes bankrupt even the crumbs will cease. The destiny of the human race appears to be at stake. The writer is careful to use the words "appears to be", because new considerations must now be taken into account, to which writers of the past have not been able to refer. But, undoubtedly, if man were never to be more able to avail himself of certain "new" sources of energy — within the atoms of the earth — than he is at present, the fate of the race would absolutely depend upon the continuance of the sun's expenditure, by which almost wholly we now live, and all our predecessors have lived.

The height of the sun's temperature excludes the possibility that that temperature is maintained by combustion, as we have already seen. But there is another argument, under this head, which is even more convincing.

Continuance of the sun's heat inconsistent with any process of combustion

Let us assume that chemical combination of the type called combustion or oxidation is possible in the sun, that this stupendous sphere is made of solid coal throughout, and that the coal has an atmosphere of pure oxygen to burn in. Even so, some 1500 years would see the end of its resources. In a word, combustion is impossible in the sun, and no combustion conceivable could maintain the sun's expenditure of energy. No *ordinary* chemical processes of any kind can explain the facts. The fatal objection of time would dispose of the combustion theory, even if combustion were possible; and it equally disposes of the view that the sun is simply a huge hot body radiating heat, as a red-hot globe of iron would, a body so huge that its radiation can continue for a very long time. Calculations can readily be made to test the possibility of this view. They show, just as the calculations of combustion show, that such an explanation would only suffice for a few thousands of years.

These two theories, and the objection to them, prompt us to ask a new question, the answer to which will contribute to the solution of our problem. *How long* has the sun been spending energy in the prodigal manner we have described? Will a few thousands of years cover the past of the sun? And may we expect that a few thousand more years will see the end of the sun's brightness and the death of the human race?

Here evidence of various kinds, astronomical, geological, biological, assures us that the sun must have been expending tremendous quantities of energy not only for some thousands of years but probably for hundreds of millions of years.

Our ignorance of whether the sun's temperature is or is not declining

Whatever we can infer from the records of the earth's past, we certainly have no evidence whatever that the sun has been cooling throughout the traceable period of the history of the earth's crust. This is not to say that the sun is not cooling. No man yet knows whether the sun is cooling, though that is probable, or whether its temperature is stationary as a whole, or whether the sun is actually getting hotter. Only, we are absolutely certain that the earth has received intensely powerful solar radiations for a very long period, the extent of which can only be guessed at; and these guesses mount into hundreds of millions of years. When we consider this factor of *time*, together with the factor of *quantity*, we see that the source of the sun's energy must be very copious — beyond our language to compass.

Yet these arguments carry us nearer to our goal. If the quantity to be accounted for, and the time during which it is to be accounted for, are so great, we can definitely assert that the sun's heat is being evolved by transformation of something wholly different "as the great ages onward roll". No original store of heat, as in the supposed case of the red-hot globe of iron, and no production of heat from the chemical energy which is liberated by combustion, could imaginably account for the scale of production.

Does the sun receive an income of heat from starlight and starheat of space?

Baffled in this unmistakable fashion, we may turn in another direction. Perhaps the sun is always receiving from without some source of energy which replenishes it — perhaps the furnace is being stoked, as it were, and the source of its energy is not stored within it at all. Now, what is there that pours into the sun, and might thus recruit its energy? In other words, granted that we cannot account for the sun's expenditure in terms of the sun's capital, *so far as we have gone*, what income may the sun be in receipt of which we had overlooked?

The sun *does* receive an income from two sources, one immaterial and the other material, and each of these has received very careful discussion in the attempt to account for the sun's expenditure. First, there is the sun's income of starlight; and second, its income of meteorites. As regards the first, we may be brief. The sun is, on the average, just as distant from the stars as we are. We may then estimate the energy of the starlight and starheat which fall upon the earth, may try to allow for the quantity that is absorbed by the atmosphere, and is not registered by our instruments at the bottom of that great ocean of air, and then we may multiply this quantity by the figure which represents the ratio of the sun's surface to the earth's. The larger surface will catch more energy, of course. The result is hopelessly inadequate; the stellar energy thus received does not begin to account for the solar energy. But the inquiry was worth making, for it reminds us of one of the great unsolved problems of astronomy: what becomes of all the energy which the sun and the other stars radiate into space, past their planets, if any?

Is the sun fed by constant showers of meteorites drawn to it?

The second source of solar income is much more important, and our interest in it today is much greater because of the prominence which the meteoritic theory of the solar system assumed in the speculations of such astronomers as the late Sir Norman Lockyer and Percival Lowell and continues to enjoy in almost all contemporaneous theories. Many astronomers incline to the view that the "fiery clash of meteorites", their collision and coalescence, converting their motion or much of it into heat, is the source of most of the internal heat of such bodies as the earth, and of the sun. And if we are to accept, or even to entertain, this view of the origin of the sun and of the original heating of the sun, may it not be that even now, as for ages past, the sun is being fed and increased by a supply of meteorites, the energy of whose motion is converted into the energy continuously spent by the sun?

We know that our small earth is yet massive enough to attract an unceasing shower of meteorites, whose energy of motion, when they strike our atmosphere, produces the light and heat of what we still speak of as "shooting stars". The sun's attraction is vastly greater than the earth's; and many meteors must surely fall into the sun, and the arrest of their motion must mean that their energy of motion is changed into those other forms of energy which are called light and heat. Doubtless meteorites still fall into the sun, and supply the sun with energy, but *how much?*

The weight of meteors needed to keep up the sun's heat for a year

We can estimate, without much difficulty, the quantity of matter that must be continually falling into the sun if this is the real source of the solar energy. Thus it has been calculated that if we were to grind the moon into fragments like meteorites, and feed the sun with them, they would maintain its radiation for something like a year. That does not take us very far. Suppose that all the planets together were to be poured into the sun. Calculation shows that, even so, less than merely fifty thousand years would see the end of the energy thus supplied.

Such calculations answer our question only too conclusively. The sun would need to catch "a moon-weight of meteors" every year to keep it going; and we can definitely say that the necessary supply of meteors is simply not to be had. We should know about it to our cost if the space of the solar system were so crowded with roaming meteoric matter as would be required to satisfy the sun's needs in this way. Besides, not only our own experience but the experience of Mercury is conclusive. If there were anything like the necessary proportion of matter moving in the neighborhood of the sun to supply him with an adequate income, Mercury would be disturbed gravitationally to an extent which, we can definitely state, does not occur. No doubt a meteoric supply does exist for a portion of the sun's energy, but it is hopelessly inadequate to explain the rate of expenditure.

Will the shrinkage of the sun account for its output of energy?

We are thrown back, then, on the sun itself. Its source of income must be from within, after all, hard pressed though we may be to find it. And the case of the meteors, impelled by gravitation, gives us a clue. The mutual gravitation of the particles composing the sun must involve collisions and heating, and this may be the source of the sun's energy. Here is a simple but colossal idea which has been discussed and examined by the greatest astronomers and mathematicians for many decades, and can be supported by a great deal of evidence. Just as the possible explanation from the meteorites at once reminded us of the meteoritic theory of the origin of the solar system, so we are now reminded of the original nebular theory of Laplace. Since his day, such minds as those of Herschel, Helmholtz, Kelvin and Newcomb have devoted their best powers to the subject. Nor need we depend upon any such theory as Laplace's. Whatever the origin of the sun and the solar system, we can deal directly with the question: does the sun contract? And with the further question: can any possible shrinkage of the sun account for its output of energy?

How long heat from shrinkage would keep the sun alive

We cannot actually observe any contraction of the sun. If modern methods had existed in remote antiquity, and we could compare our records with those of, say, eight or ten thousand years ago, possibly something might be learned. Our successors will be better off in this respect. But though we cannot appeal to actual observation, we know that gravity tends to make the sun contract, and such contraction liberates energy. And, just as in every one of the possibilities already examined, only to be rejected, we have merely to ask one more question, but that is a crucial one: how long would the sun's contraction maintain its expenditure of energy? The answer to this question has been accounted satisfactory until very recent years, and for a considerable time.

Thus, Sir Robert Ball, when writing in 1886, could accept the contraction theory in these words: "It is one of the achievements of modern science to have effected the solution of the problem — to have shown how it is that, notwithstanding the stupendous radiation, the sun still maintains its temperature."

And there the answer to the great problem remained until our own century. Once again, however, we find that the twentieth century is opening out new realms of knowledge undreamt of by the best wisdom of the most recent past; and the accepted theory of the sun's energy must be now revised in the light of our new knowledge.

Revision is necessary, because when the test of time, which has been fatal to all our other theories, is applied to this one, it breaks down too. Certainly it stands the test far longer than any of the others did. The best of them would only avail for a few thousand of years, but this would avail for some millions.

The hopeless inadequacy of shrinkage to account for the sun's career

Even in the early years of the present century there was much more to be said in favor of the gaseous-nebula theory of the solar system, as described in Chapter 9, than we can now accept. It seemed quite legitimate to assume that the sun is the shrunken concentration of a mighty nebula — the "solar nebula" — which once extended as far as the orbit of Neptune; and calculations are possible which afford us some idea of the energy such a nebula would contain — energy which, by the gravitational contraction of the nebula, might be transmuted into the energy of the present sun, that we feel and see. Of course, there is no certainty in all the *data* whereupon these calculations are based. But still we know enough to afford us some measure of the possibilities; and the result is that we find ourselves with an explanation of the sun's energy that may avail for, perhaps, twenty-five millions of years as to the past, and some ten million years for the future. But "so short a time" is looked on by most scientists as hopelessly inadequate.

These estimates seem less adequate now than they did only fifteen or twenty years ago, when men of science were still quoting Lord Kelvin's guesses at the age of the earth and the sun. Those estimates varied widely among themselves at different times, according to the various assumptions on which Lord Kelvin based them, and they are so far outstripped by more recent estimates as to retain scarcely more than historical interest. Still, we may note that one hundred millions was a figure which Lord Kelvin gave at one time — too high, we observe, to be accounted for by the contraction theory of the sun's energy, as estimated above. But modern work has taught us that all these nineteenth century guesses were far short of the truth. So much the worse, today, for the contraction theory of the sun's energy: and hence we must look for further sources of the solar heat.

Where action between atoms fails, may not action within atoms succeed?

The reader who remembers a very early chapter in this section will already have asked himself a question which occurred to men of science all over the world a few years ago. Everything hitherto has failed us — the radiation of a very hot and very large body; combustion or any other form of chemical action hitherto recognized; the reflection of starlight; maintenance by meteorites; even gravitational contraction. But all the while there was a source of energy, immeasurably greater than any we had thought of, which was perfectly available, but of which we did not even know the existence. We were still thinking of the atoms of the sun as tiny, hard, inert things, which went where they were pushed or pulled, and could only give expression to energy, energy of motion, chemical energy, or what not, that somehow existed outside them. Chemical action was out of the question at a temperature like the sun's; and by chemical action we meant (and still mean, though indeed knowledge has outrun language) the action *between* atoms. The idea of action *within* atoms was to be counted as inadmissible.

Discoveries about radium suggest solar output of energy immeasurably long

But radium the revealer altered all that. The Curies, in probing pitchblende, found still another secret of nature which may help us in explaining the wealth of energy possessed by the sun. For in pitchblende there was found radium, and radium is an element composed of atoms which explode, *giving off energy*. This is not "chemical action", as we had understood it, but it reduces all the chemical action ever dreamed of to a mere negligible trifle. It is as if by far the greater part of all the energy of the universe had been invested in building atoms, and only a trifle had been left over for use outside them. Now, the explosions of radium atoms, dispersing the energy which was deposited by the Author of nature in the vaults of the atoms when they were made, are unaffected by such trifling considerations as the difference between the temperature of frozen air and that of the electric furnace, though that is difference enough to affect profoundly all the ordinary chemical operations we know. But since these great variations induce no change in the steady progress of intra-atomic activities, we may surmise that if there are radium atoms in the sun the temperature to which they are there subjected would not interfere with their production of energy.

The presence of helium in the sun a suggestion that radium is there

"Is the sun made of radium?" was a question put by many amateurs of science. Certainly not, the student could reply, for, if it were, we should not be here. But if there were in the sun even a very small proportion of radioactive materials, *that* might yet be sufficient to supplement the other sources of the solar output of radiant energy, and to prolong its duration for almost as long a time as anyone might care to name, so gigantic is the revelation of unsuspected resources which one glance within the atom reveals. Hence, it would appear, we must set ourselves to the question of determining whether there is radium in the sun.

Every probability points in that direction. Numerous other elements, as we shall see later, are found in the sun and in the earth. We believe that the sun and the earth are of common origin. The element helium is now known to be one of the products of the decomposition of radium and of other radioactive substances. The presence of helium in the sun, where it was first discovered and for that reason so named, is therefore a striking bit of evidence in favor of the view that radium must be there, too. But, of course, that is not conclusive evidence, and we are bound to look for direct demonstration of the presence of radium in the sun. We must do so, however, with very moderate expectations. Radium is an exceedingly scarce constituent of the crust of the earth. It *must* be an exceedingly scarce constituent of the sun, if it be present there at all, for the simple reason that otherwise the sun would be far hotter than it is. The study of the spectrum of the sun has so far failed to detect evidence of radium, although this, of course, does not definitely prove its absence.

Radioactivity in the sun a new key to the secret of its energy

We need not, however, be disconcerted at this, for we have been assuming that only radium can supply us with atoms capable of evolving energy from their interiors. But radioactivity is in all probability a general phenomenon of matter. Many radioactive elements besides radium are now known; and we have every reason to believe that, if we find some elements not radioactive, the simple reason is that we have not observed them for, say, half a million years or more. Every kind of atom has its own characteristic rate of evolution, just as the individuals of any living species have a particular and characteristic longevity — that is all. Thus our decision as to this new theory of the sun's energy does not hang upon the demonstration of radium or of any other one of the various elements in the sun. That the sun is radioactive to some degree is no longer doubted: and hence we have a new explanation of its prodigious energy.

THE SMILING EARTH GIVES UP HER RICHES TO MANKIND

"THE HARVEST OF THE EARTH AND THE GATHERING OF THE FRUITS THEREOF." From a painting specially made for The Book of Popular Science by Stephen Reid

The vast expansion of modern ideas owing to the discovery of intra-atomic energy

This, of course, is not to say that the other explanations, already discussed, do not contribute — each in its own degree — to the sun's resources. But the discovery of radioactivity has itself compelled us enormously to extend our time-scale of the solar system, and therefore of the energy expenditure of the sun; and the concomitant discovery of intra-atomic energy, of which radioactivity is known to be the expression, helps us to explain the source whence the sun supplies the demands made upon it by our modern ideas of the length of the past during which this expenditure has been maintained.

We are here at the very limits and outposts of human knowledge. To be more detailed or more dogmatic would be to court inaccuracy. But we are already sure enough of the essential facts for us to see that they are the basis for a newer and deeper interpretation of the skies and their phenomena than anything of which the past could dream — newer and deeper not at all in the sense of superseding or annulling the gravitational and telescopic astronomy of our predecessors, to whom we are indispensably indebted. The second half of a pair of scissors is worth no more than the first, but rather more than doubles its usefulness. So here we feel that the addition of the theory of radioactivity to the knowledge bequeathed us by the nineteenth century gives us a completer, perhaps a complete instrument, with complementary halves, which will cut the veil of ignorance in twain.

The story of the sun as an introduction to the study of the problem of starlight

Early in this chapter it was said that astronomy asks no more important question than that of the sun's source of energy, for two reasons, the first of which was that the sun matters so much for mankind.

The second reason was not stated. It is that the sun is a star, and that any really valid answer to this question as regards the sun, our star, throws sunlight indeed upon the dim and distant problem of starlight! Of all the millions of stars there is just one which is placed beside us. If ever we are to understand them, in their all but infinite remoteness, it will be by our study of the one example which we can almost handle — an assertion not too strong if we remember how the modern astronomer, in his laboratory, can pull sunlight to pieces to see what it is made of. Hence our study of the sun is necessarily, in large degree, a study of all the stars.

This new development illustrates yet again that the greater the growth of the sphere of knowledge the greater is its area of contact with the unknown. All manner of conclusions, based upon the view that only such and such forces had to be reckoned with, must be restated after we have tried to reckon in radioactivity as well. In the case of the stars and nebulæ this will be a very long and difficult task. The first step towards its fulfilment is to learn all we can regarding the condition of sunlight. The curious fact is that we see far more deeply into the sun when we analyze its light than when we look at it by its light. Hence the modern study of the sun is above all spectroscopic, but to the spectroscope we must add all the imaginable apparatus which will help us to determine, from the sun's light, the facts of its radioactivity.

With this key we shall hope to interpret the stars, in some degree. But we must beware of supposing that, *this time*, we have got final methods, final instruments, final results. That is what the nineteenth century was always thinking. In the face of radioactivity we realize that all the astronomical work done hitherto is little more than a preliminary survey of the field! But radioactivity occupies, for us, just the place that the law of the conservation of energy did in the middle of the nineteenth century, and the law of gravitation a few generations before. Each in its turn was thought to be the key to all things. But that is not the true history of human knowledge. Each key that is to unlock all things is discovered, in the long run, to be chiefly valuable because, on using it, we find ourselves possessed of a new key, demanding to be used in its turn.

IN THE PATH OF A WHIRLING CYCLONE

Courtesy Weather Bureau, U. S. Department of Agriculture

AN APPROACHING CYCLONE

These two photographs were taken in immediate succession, the upper first, at Elmwood, Nebraska, on April 6, 1919, by B. G. Pickwell, who was very near the path of the tornado.

ATMOSPHERIC MOVEMENTS

How the Heat and Flow of the Air are Measured and Weather Wisdom Sought

GALES FROM THE WHIRLING EARTH

WE may ignore the weight of the air, or its humidity, or its radioactivity, but its temperature forces itself upon our notice. A temperature of 125° F. in the shade, or −40° F., refuses to be ignored. Nor is the temperature of the air important merely in its relation to our skin and our circulation; it has such far-reaching consequences as tempests and typhoons, as trade winds and anti-trade winds. Heat it was that took Christopher Columbus to America, just as certainly as it is heat that today takes our great liners across the Atlantic.

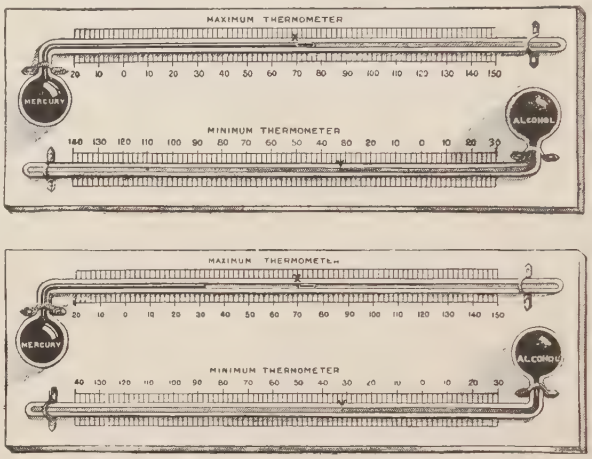
Before, however, we discuss the far-reaching consequences of the heating and cooling of the air, it will be well to look at the thermal facts themselves. In the first place, how is the intensity of heat measured? Usually by means of instruments known as thermometers, which are constructed on principles we shall now briefly describe.

The ordinary thermometer consists of a little bulb ending in a narrow closed tube. There is enough mercury in the instrument to fill the bulb and extend some way up the closed tube. The tube above the limit of the mercury is emptied of air, so that it is practically a vacuum. When heat is applied to this bulb and tube of mercury, the mercury expands, and the upper limit of the mercury in the tube rises, and rises in proportion to the heat applied. By grading the tube accordingly, and marking the point to which the expanding mercury rises, we can measure the temperature. Instead of mercury some other expansile liquid such as alcohol may be used.

Two thermometers, differing in their graduation, known respectively as Fahrenheit and centigrade, are in common use today. The former, named from its inventor, divides the extent of expansion between the freezing and boiling points of water into 180 degrees, and, marking the freezing-point 32, marks the boiling-point, accordingly, 212. Its zero is thus 32 degrees below the freezing-point of water. The centigrade thermometer, on the other hand, divides the expansion between the freezing and the boiling points of water into 100 degrees, and, marking the freezing-point zero, marks the boiling-point 100 degrees. A hundred degrees on the centigrade scale thus equal a hundred and eighty degrees on the Fahrenheit. On both thermometers the degrees are marked up beyond the boiling-point, and down below the freezing-point. Mercury freezes at −40° F., *i.e.* 72 degrees below the freezing-point of water, and therefore for recording very low temperatures an alcohol thermometer is better than a mercury. In the Réaumur thermometer, little used, the freezing-point of water is marked zero and the boiling-point 80°.

Thermometers are graduated by first plunging them into melted ice, and marking the point to which the mercury or other liquid contracts, and then putting them in the vapor of boiling water, and marking again the point to which the mercury or other liquid expands. Allowance must be made for variation in the boiling-point due to varying atmospheric pressure. The length so marked is then divided into 80, 100, or 180 degrees, according to the scale to be used.

Thermometers are also made which continuously register the temperature by means of a pen tracing on a moving drum. In one type of these so-called thermographs an expansile liquid fills a curved, closed tube, and as the liquid expands it straightens the tube in its effort to make more room. One end of the closed tube is fixed, but the other end is free, and to this free end is attached the registering pen to record its movements; and its movements recording the expansile movements of the tube necessarily record the intensity of the heat to which the liquid has been exposed. Thermographs based on the change in shape of a curved strip composed of two metals having different coefficients of expansion, are more common in this country.



THERMOMETERS THAT RECORD HEAT AND COLD

These pictures show the working of maximum and minimum thermometers, the indicators, *x* and *v*, marking the highest and lowest temperatures reached. In the upper picture the minimum thermometer is at 32°, the lowest point reached overnight. The alcohol carried the indicator, *v*, to this point, and left it there when the temperature rose, as in the lower picture. In the maximum thermometer of the lower picture, the mercury is at the supposed highest temperature of a day. It has pushed the indicator, *x*, to 70°, and when it shrinks to a lower temperature, as in the upper picture, the indicator is left at 70.

In order correctly to determine the temperature of the air, the thermometer must be screened from the direct rays of the sun, since the sun would heat the thermometer much more than it heats the air. The sun's rays, indeed, pass through the air and heat it comparatively little, and the heat of the air is due more to the radiation of heat from the earth than to the direct rays of the sun. As we ascend above the earth up to about seven miles, the temperature of the air steadily falls. Thus a free balloon carrying a self-registering thermometer which was sent up from Trappes, in France, when the surface temperature was 50° F., registered a temperature of — 58° F. at a height of six miles; one from Strassburg, at a temperature of 43.3° F., registered — 65° F. at about the same height.

Apart from height, the temperature of the air is in proportion to the direct heat of the sun; and this, as we have already explained, varies with the obliquity of the sun's rays. But the temperature of the air also depends on the nature of the surface on which the sun-rays fall. Thus land is more quickly heated by the sun than water, and radiates heat to the air more quickly. Water, on the other hand, stores more heat than land, and radiates heat to air when the land is quite cold. It is for this reason that the sea modifies both the heat and the cold of the land, and that inland places have greater extremes of temperature than places by the sea. The sandy soils of deserts may be heated almost to 200° F. by the sun, and when the hot sand is raised by simooms the temperature of the air may rise to 125° F., or even more.

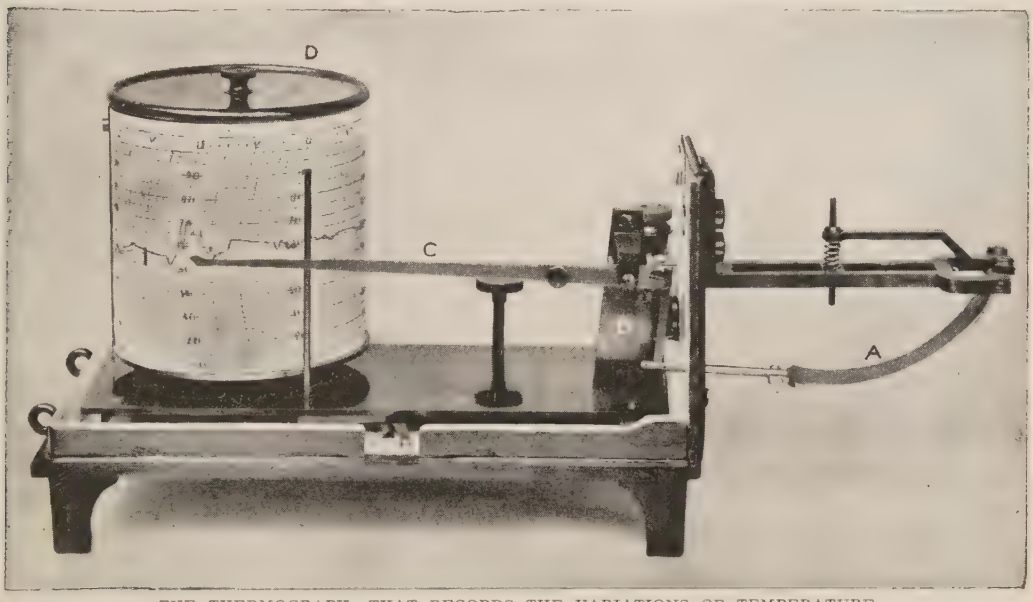
Such disturbing factors as these, especially the irregular distribution of land and water, render the distribution of heat rather irregular, and only in a rough and general way can we assert that the nearer the equator the greater the heat. Meteorologists have constructed very interesting maps with lines known as "isothermal lines" running through places with the same mean annual temperature, and these lines are found to have wavy, undulating courses, and not to run parallel to the equator. The median line of the zone of greatest mean heat is found to run not through the equator, but slightly north of it, and its margins are wavy, with tongues running northward into India, and southward into Africa and South America. In January the Shetland Islands are on an isotherm that runs through our Southern States, in July on one through Alaska.

The atmosphere, then, is heated in this irregular manner by the sun, and the result is wind. Were it not for the unequal heating of the atmosphere, it would be stagnant as a mill-pond; but the sun heats and expands it and fills it with water-vapor, and gives it tides and currents like a sea.

The great currents of the atmosphere are the "trades" and the "anti-trades", and they are simply hot and cold currents of air running between the poles and the equator, and deflected by the motion they receive from the whirling earth. Let us look into the physics of these great heat-currents.

tom in a room with heated air. The heated air pours out at the top and the cold, denser air rushes in at the bottom to restore the balance. The heated expanded air, indeed, may be regarded as a partial vacuum.

The heated upper air floating north and south from the heated zone constitutes the anti-trade winds, while the cold currents flowing from the poles are the trade winds. The trade winds run north and south from the poles, and the anti-trade winds north and south from the equator, but in no case is the direction due north or due south. How is this?



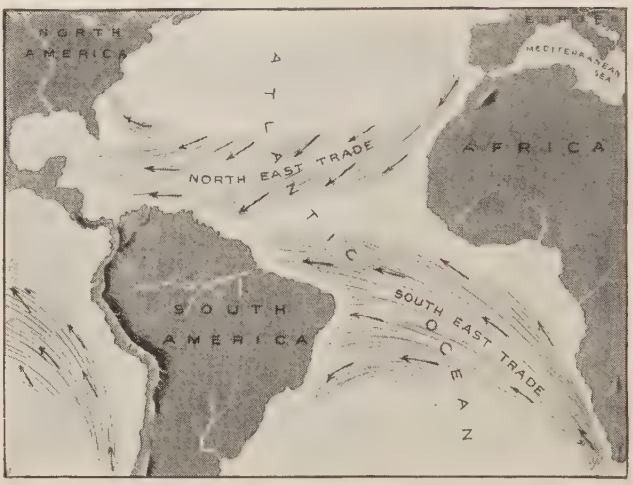
THE THERMOGRAPH, THAT RECORDS THE VARIATIONS OF TEMPERATURE

The curved tube, *A*, is filled with liquid which, as it expands and contracts, moves the marker, *C*, up and down, by means of the levers at *B*. On the drum, *D*, revolved by clockwork, is a chart on which a week's record of the variation of temperature has been marked.

The hottest air is that in the belt we have already mentioned which runs round the earth a little north of the equator, and this belt is the mainspring of the great atmospheric current. The air of this belt being heated and laden with moisture, expands and rises, and is heaped up above the general surface of the atmosphere. Naturally it does not remain heaped up, but flows away towards the poles, while the heavier, colder, denser air from the poles rushes along the surface of the earth toward the equator in an effort to restore equilibrium. It is much the same as happens when a window is opened top and bot-

Let us consider the relation of the atmosphere to the earth's rotation. The atmosphere is bound to the earth by gravitation, and, apart from disturbing factors, earth and atmosphere turn together as if a continuous whole. The atmosphere above the equator whirls round with the equatorial belt, which, as is well known, is larger than the polar belt. The atmosphere, likewise, in the Arctic Circle whirls round with its smaller circle of latitude, completing a much smaller circuit in twenty-four hours, and therefore moving much more slowly than the air above the equator.

In general, therefore, it is plain that the atmosphere moves more and more slowly in its eastward rotation with the earth the farther we recede from the equator, and the nearer we approach the poles. Now, hot air rising from the equator and flowing towards the North Pole retains as it flows the rapid eastward motion it had when it started; and this motion as it reaches northern latitudes is quicker than the motion of the surface of the earth in these latitudes. Accordingly, the air flowing northward deviates eastward across the more slowly eastward-turning surface of the earth. That is to say, it seems to come from the southwest and to be a southwest wind. Hence the "anti-trade" flowing in the upper atmosphere northward from the equator is a southwest wind. The "anti-trade", again, flowing southward from the equator, becomes on the same principle a northwest wind.



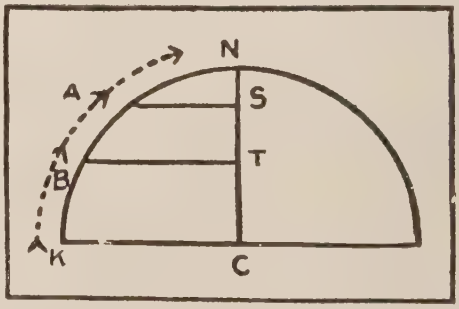
THE DIRECTIONS OF THE ATLANTIC TRADE WINDS

Let us see next in what direction the trade winds deviate, and why. The north trade wind starts from the northern portions of the globe, and flows in the lower layers of the atmosphere towards the equator. It starts with a very slow eastward drift, since in the northern latitudes the atmosphere is carried only slowly eastward, and the result is that, as it flows southward, the more quickly rotating lower latitudes outstrip and pass it. The result is a wind that seems to come from the northeast. This is not quite easy to understand at first, and an illustration will make it plainer. Suppose a steamer proceeding east at twenty miles an hour, and a west, or fair, wind blowing eastward at ten miles an hour, in what direction will the wind seem to be to people on the deck of the steamer?

Obviously, though the wind is really west, the quicker motion of the steamer creates an east wind, and the passengers will be mislead into thinking that is the wind's direction. In just the same way, though the trade wind is coming from the west and going eastward, the earth is rotating eastward faster still, and so outstrips the west wind, and creates an east wind of its own. In like manner the trade winds blowing from the South Pole appear as southeast winds.

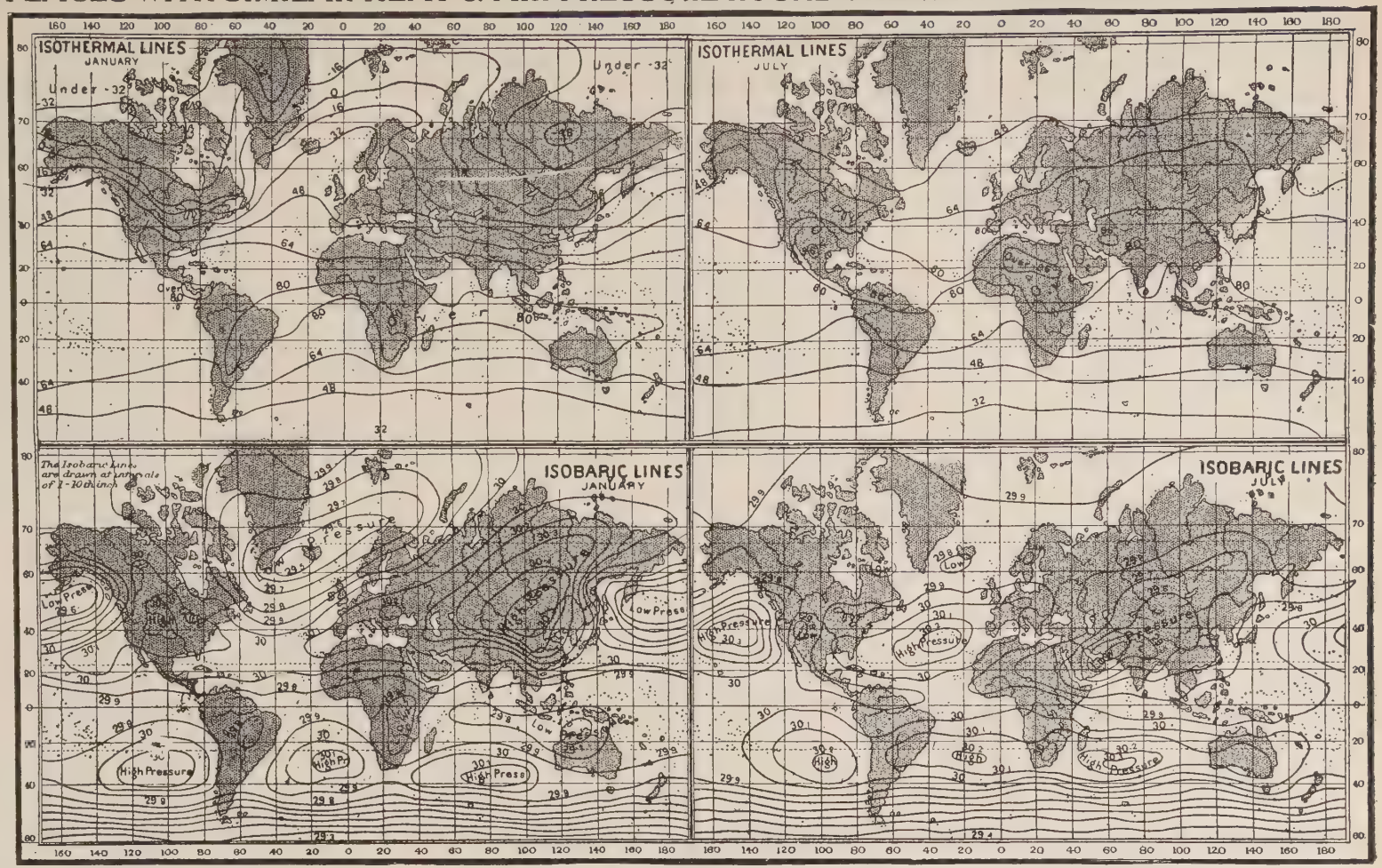
We have said that the trade and anti-trade winds retain the velocity imparted to them at their start by the velocity of the earth. If we toss up a ball in a moving railway train, the ball retains the forward momentum imparted to it by the train, and falls on the floor of the car, even though the floor be moving at sixty miles an hour. And on the same principle the wind retains its initial velocity.

But in the case of the trades and anti-trades, an additional law comes into play. As the trade winds proceed northward they approach nearer and nearer the axis of rotation of the earth. *NC* being the axis of rotation of the earth, and *KBA* being



the trade wind at various stages of its northward journey, it is plain that *BT* is less than *KC*, and *AS* less than *BT*.

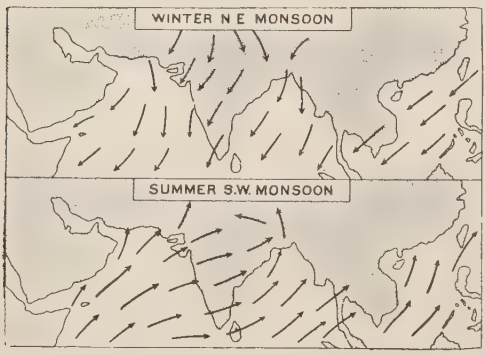
PLACES WITH SIMILAR HEAT & AIR-PRESSURE ROUND THE WORLD & THROUGH THE YEAR



ISOTHERMAL LINES SHOWING HEAT OF EQUAL INTENSITY ALONG THE COURSE OF EACH LINE, AND ISOBARIC LINES GIVING BAROMETRICAL PRESSURES

This approach of the wind nearer to the center of rotation quickens its speed. To illustrate: if we tie a weight to a stick by a string, and whirl the weight round so that the string winds up, the weight circles the stick more quickly as the string shortens. Thus the trade wind not only retains its initial velocity, but acquires more speed eastward as it proceeds northward. By the same law, the anti-trades coming from the poles towards the equator, and receding from the axis of rotation as they proceed, must slow down.

At the surface of the earth the northeast trades are found to prevail from about 29° north to 7° north latitude, and the southeast trades from about 3° to 20° south latitude. Between these trade winds there is a belt of calms varying in width



THE MONSOONS OF SOUTHERN ASIA

from 150 to 500 miles; the average position of the middle of this belt, called by sailors the "doldrums", is in latitude 5° north. On the outer margin of the trades there are two other regions of calm, called the "horse latitudes", and beyond these we find again in the northern hemisphere prevailing southwest winds and in the southern hemisphere prevailing northwest winds. The calms of the horse latitudes are due to the cooling of the anti-trades which descend and interfere with the trades.

Though a great part of the anti-trade wind cools and descends, there is always an upper layer which proceeds towards the poles, and on the tops of all high peaks we can always find eastward anti-trades, even when northeast or southeast trades are blowing below; and volcanic dust and clouds when high in the air go eastward.

After the trades and the anti-trades, which are constant or regular winds, come the seasonal or periodic winds such as the Indian monsoons which are produced as follows. The land becomes so heated during the summer time that the air over it becomes hotter than the equatorial air, and accordingly hot air is drawn from the equator to India. Again, since the air drawn from the equator retains its great equatorial eastward velocity, the wind seems to come from the southwest; hence we have in summer the southwest monsoon. In winter the current is reversed, and there is a northeast monsoon blowing from the land.

It may be a little difficult at first to understand the behavior of these great winds, but the general principles of their movement is clear: they are the results of the irregular heating of the earth's surface by the sun, and the deviation in direction, owing to the rotation of the earth, is of secondary importance.

Not only the great winds but the small winds are due to inequalities in heat. In the daytime on the sea-coast there is a breeze from the sea, since the land is hotter than the sea, and heats and expands the air over it, but after the sun sets, and the heat has radiated from the land, the sea is hotter than the land, and a breeze therefore blows from the land to the sea. Again, at high altitudes during the day, when the high land is heated by the sun and rendered hotter than the plains, a breeze blows uphill from the cooler valley land, but at night, since the high land grows cool more quickly than the low land, the direction of the wind is reversed. The *mistral* of the Riviera is a cold northwesterly wind which rolls down on the plains from the cold summits of the Cevennes and the Maritime Alps.

But, besides the great trade and anti-trade tides, and the fluctuations due to such known alternations of heat and cold as we have mentioned, the ocean of air, like the ocean of water, is full of traveling whirls and eddies of various sizes, and it is these that constitute the ordinary winds and gales, and to a great extent determine the weather.

Any considerable alteration whatever in local air-pressure, whether the alteration be due to heat or water-vapor, or both, is followed by wind. If the pressure be lowered, air flows in all round to equalize the pressure; if the pressure be increased, air flows outwards to restore equilibrium. The inward flow of the air toward a center of low pressure is called a "cyclone", or cyclonic movement, and the outward flow of the air from a center of high pressure is called an "anti-cyclone", or anti-cyclonic movement.

In both cases, however, the air does not flow straight in or straight out, but proceeds in a spiral course. The spiral motion is caused by the earth's motion, and varies in direction. In the northern hemisphere the spiral whirl of a cyclone flows inwards in a spiral which turns in the opposite direction to the hands of a watch; while the spiral whirl of an anti-cyclone turns in the other direction. In the southern hemisphere, on the other hand, cyclones and anti-cyclones whirl in just the reverse directions, the southern cyclone turning in the direction of the hands of a watch.

HOW WIND AND RAIN WEAR AWAY ROCK

In this fragment the softer limestone has been worn away, leaving the harder fossils imbedded in it to stand out in relief.

The following practical rule, known as Professor Buys Ballot's law, gives the direction between wind and pressure for the northern hemisphere: "Stand with your back to the wind, and the barometer will be lower on your left hand than on your right; hence it follows that if you stand with the high barometer on your right and the low barometer on your left, the wind will blow on your back. In the southern hemisphere the rule must be reversed, 'right' put for 'left' and 'left' for 'right'."

An anti-cyclone, commonly called a "high", is usually a very stationary eddy, and the air descending in its spiral is free from moisture; it is thus usually associated with good weather. In summer anti-cyclonic weather is calm, cloudless and sunny; and in winter, calm, cloudless and frosty.

A cyclone is not a stationary eddy; it is always moving, and sometimes moves at a great rate. It usually brings rain and cloudy weather, since the vapor in the rising air condenses as it rises.

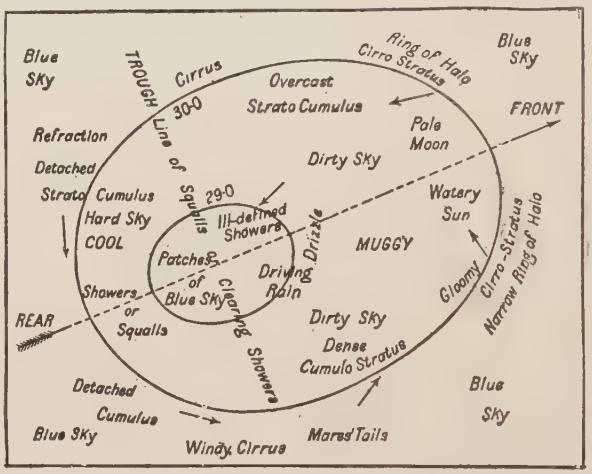
Since fall of pressure is usually associated with bad weather, and rise of pressure with good, barometers evidently may be used to foretell the weather. But in most cases the important thing is not the mere rise and fall, but the rise and fall relatively to surrounding areas, and this can be found out only by a comparison of local readings; and nowadays such comparison is made by charting on a map a collection of readings telegraphed by various meteorological stations. In this way we can draw curved lines of equal pressure, which are called "isobars", and the charts so drawn will show cyclones or anti-cyclones as in the diagrams. The Weather Bureau publishes every day a map of this kind for the United States and from it the weather forecast is made.

Isobars are usually drawn to indicate successive differences of pressure equal to that of one-tenth of an inch of mercury. The closeness of such isobars is evidently an indication of the gradient of the fall, which is stated as so many hundredths of an inch of barometric pressure in a distance of 60 nautical miles (one degree).

Thus, if two barometers 60 miles apart differ by $\frac{3}{100}$ of an inch, the gradient is said to be 3. The deeper the depression and steeper the gradient, the stronger the wind.

Thus, from a weather chart we are able to foretell weather to some extent. If we know that the central depression of a cyclone is advancing in a certain direction, at a certain rate, we can tell approximately its future course, and the date of its arrival at various districts.

When a cyclone has a very deep and steep central depression, and whirls and advances with great rapidity, it becomes what is known variously as a typhoon, hurricane, whirlwind, simoom or tornado. Such violent whirls are always caused by the rapid local heating of the lower layers of air, so that a column of hot air rushes up like that which belches from a furnace chimney. Miniature tornadoes are often seen whirling about on hot deserts, or even on hot roads, raising little fountains of dust as they whirl.



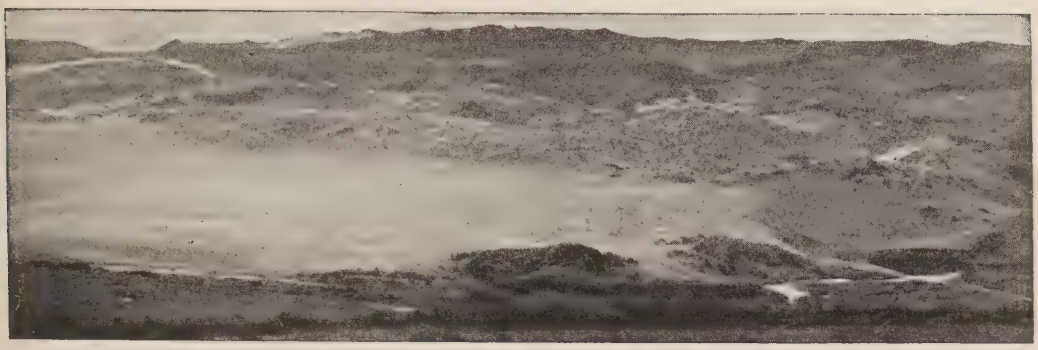
THE WEATHER OF A TYPICAL CYCLONE
(After Abercromby and Marriott — from the *Quarterly Journal of the Meteorological Society.*)

In Europe, North America, the West Indies, the China Sea, the Bay of Bengal, on the east coast of Africa and in the Sahara, violent and destructive cyclones are far from uncommon. The late Professor N. S. Shaler thus described a destructive North American cyclone:

"In its path over the surface, the circling movement of the writhing air, and the sucking action of the partial vacuum in the center portion of the shaft, combine to bring about an extreme devastation. On the outside the whirl of air, which rushes in a circling path towards the vortex, overturns all movable objects; and in the center these objects, if they are not too heavy, are sucked up as by a great air-pump. Thus the roofs of houses, bodies of men and animals, may be lifted to great elevations, until they are tossed by the tumultuous movements beyond the limits of the ascending current, and fall back upon the earth. When the center of the whirlwind passes over a building, the sudden decrease in the pressure of the outer air often causes the atmosphere which is contained within the walls suddenly to press against the sides of the structure, so that these sides are driven quickly outwards as by a charge of gunpowder."

The following account of a tornado in Minnesota is taken from Ferrel:

"The tornado struck the Mississippi River at a point opposite to the village of Sauk Rapids, and fishermen who were in full view of the crossing aver that for a few moments the bed of the river was swept dry; and in corroboration of this remarkable statement they showed me a marshy spot where no water had been before this event took place. Two spans were torn away from the substantial wagon-bridge below the rapids, one span being hurled up-stream and the other down it by the rotatory motion of the blast, great blocks of granite being also torn bodily out from the piers. The large flour-mill near the bridge was leveled. The depot of the Northern Pacific Railway was demolished, and the central portion of the village itself was attacked with the greatest violence. Being the county seat, the courthouse was located here, a substantial structure, of which only the vault, six iron safes and the calaboose were left — the latter turned upside down. A fine new schoolhouse, costing $15,000, was completely swept away. The Episcopal church was so utterly ruined that the sole relic thus far found is a



SAND DUNES INVADING THE LAND AND FORCING BACK CULTIVATION ALONG THE COAST

battered Communion plate. The floor of the skating-rink is all that is left of that structure. Stores, hotels, a brewery, and four-fifths of the residences in the village were scattered as rubbish along the hillsides, or borne away for miles through the air."

Another sensational example occurred in Illinois on June 4, 1877, where a man saw a tornado strike his house, and "the house appeared to go up bodily and plunge into the cloud. Only a very small portion of it was ever seen afterwards."

The average rate of surface wind on land is from six to twelve miles an hour. On sea and at high altitudes the velocity of the wind is greater; and in winter the cirrus cloud, which is one of the upper clouds, travels over ninety miles an hour. Tornadoes sometimes go hundreds of miles an hour. Winds are named breezes, gales, etc., according to their rate; and the following table gives the relation between their names and velocities:

Description of Wind	Velocity
Calm	3 miles per hour
Light air	8 " " "
Light breeze	13 " " "
Gentle breeze	18 " " "
Moderate breeze	23 " " "
Fresh breeze	28 " " "
Strong breeze	34 " " "
Moderate gale	40 " " "
Fresh gale	48 " " "
Strong gale	56 " " "
Whole gale	67 " " "
Storm	75 " " "
Hurricane	90 " " "

The winds of the world are the daughters of the sun, and are full of the sun's energy; and a good deal of the energy of the sea, its waves and its currents, are due to the action of the wind.

SAND DUNES THAT ACT AS A DEFENSE AGAINST THE SEA, AND ALSO SHIELD CULTIVATED LAND

Every puff of wind means a wave; it pushes the water before it into a heap, and this swings up and down and is repeated across the sea. Strong winds make huge waves, but waves are never mountains high; the highest measured were only 50 feet from trough to crest, with about 400 yards between successive crests. But the wind does more than produce waves; it also produces what is called "surface drift" — *i.e.* it drives the top layer of water before it and, in fact, skims the surface of the sea as one skims the cream off milk. In this way currents are set up in various parts of the ocean which, more or less, agree in direction with the direction of the prevailing wind. Pieces of wood and nuts and seeds are sometimes carried right across the Atlantic by surface drift, and, as is well known, Columbus received his first intimation of the nearness of land through objects drifting in the Atlantic. The best-known surface drift current is the Gulf Stream but, as we shall see when we come to deal with the ocean, there are many smaller currents all over the world.

When the wind blows off the land the sea near shore is colder, as bathers know, than when it blows landward. The reason of this is that a seaward wind blows the warm surface layers seaward, off the top of the sea, while a landward wind drives the warm surface layers landward.

The wasting power of wind-blown sand over rocks

When we come to speak of climate, we shall see that the direction of the prevailing wind is a very important factor in climate. All meteorological stations possess instruments called anemometers, which register automatically the force and the direction of winds.

The wind troubles not only the sea — it also gnaws away at the land. Even as it carries along the salt spray of the sea, so does it carry along the sand of the seashore. On a windy day the wind along the shore is full of sand, and this sand is nature's file and sandpaper, wherewith she polishes and glazes the rocks and crags of the sea-coast. But not only does the sandpaper polish — it also wears away.

Window-glass along the shore at Cape Cod, for example, loses its transparency in a day or two and is sometimes cut through in a month by the storm-driven sand. Telegraph poles in Southern California have been cut down by nature's sand blast and hard rocks in many places carry the autograph of the prevailing sand-laden winds.

By the accumulation of sand, again, hillocks of sand, or "dunes", are formed. Around the Gulf of Gascony, in France, there is a long, ridged dune almost 300 feet high at its highest point; and the dunes of Cape Bojador, on the northwest coast of Africa, and of Cape Verde Island, attain a height of from 390 to almost 600 feet. The usual habitat of dunes are the sandy shores of seas and large lakes, sandy valleys and broad sandy plains. So we have dunes at many points on the Atlantic Coast and along the shores of Lake Michigan.

But sand does not always end in dunes; sometimes it invades fertile country and overwhelms, as in Bermuda, gardens and fields and woods. On the west coast of Europe, from the Pyrenees to the Baltic, blown sand advances landward at the rate of three to twenty-four feet annually, overwhelming houses and fertile fields in its advance. On the shores of Lake Michigan, the sand has covered swamps and forests, and even low hills.

The entombed cities of antiquity and their concealed history

But not only along the sea-shore are the effects of sand carried by wind noticeable. The same things happen in the great deserts of the world, such as in the Sahara, the center of Asia, and the interior of Arabia. In Mesopotamia and Central Asia many ancient cities lie entombed in sand, carried by wind from the desert, such as the famous cities of Nineveh and Babylon, Ur and Erech, and innumerable towns have been buried on the west bank of the Nile between the Temple of Jupiter Ammon and Nubia. It is likely that the chief discoveries of the future which will throw light on the disconnected history of the peoples of the East lie hidden at this moment under the sands from Mesopotamian and Arabian deserts.

ASTRONOMERS II

WILLIAM CRANCH BOND—A WATCHMAKER WHO FOUND MANY COMETS
NATHANIEL BOWDITCH—NAVIGATOR AND ASTRONOMER
TYCHO BRAHE—WHO WOULD NOT BELIEVE THE EARTH REVOLVES
GIOVANNI CASSINI—THE MAN WHO "WROTE HIS NAME ON SATURN"
AGNES MARY CLERKE—A WOMAN WHO COULD MAKE ASTRONOMY PLAIN
COPERNICUS—A MODEST POLE WHO REDISCOVERED THE EARTH'S ROTATION

WILLIAM CRANCH BOND
A Watchmaker Who Found Many Comets

WILLIAM CRANCH BOND, the pioneer astronomer of Harvard University, was born at Portland, Maine, September 9, 1789. His father being a watchmaker, he was educated to this trade, but in 1806 an eclipse of the sun confirmed his leaning towards astronomy, and from that time forth every spare moment was devoted to the study of the heavens. He built at his home, in Dorchester, Mass., one of the first private observatories in America.

In 1815 he was commissioned by Harvard to visit the chief observatories of Europe in order to prepare designs for the new observatory which the oldest university in the United States was about to establish at Cambridge. The opening of this observatory was delayed for many years owing to lack of funds, but an excellent telescope was at last erected in 1847. With this instrument the discoveries of Bond and his son and assistant, George Phillips Bond, were very numerous and of first-class importance. They included the discovery of the inner dusky ring of Saturn, and much information as to the nature of the outer rings; as also the discovery of the eighth satellite of Saturn. Seventeen new comets were also described by the Bonds.

William Bond was one of the first astronomers to adopt photographic methods in the study of celestial phenomena, and by means of the camera made valuable observations of the sun, moon and stars. He also invented the commonly used method of recording electrically upon a chronograph the beats of a clock, together with the observed transit of stars over the wires of a transit instrument. With their great telescope the Bonds were the first to succeed in resolving the Orion and the Dumb-bell nebulæ. They also were the first to compute the distances and angles of the stars in the Hercules cluster. The father died January 29, 1859, the son in 1865.

NATHANIEL BOWDITCH
Navigator and Astronomer

NATHANIEL BOWDITCH, a distinguished American astronomer, was born at Salem, Massachusetts, on March 26th, 1773. His ancestors for three generations had been shipmasters and his father, on retiring from that "perilous mode of hard industry", carried on the trade of a cooper, by which he gained a scanty subsistence for a family of seven children. Nathaniel had to forego the advantages of school (such as they were then) at the early age of ten years, that he might go into his father's shop and help to support the family. He was soon transferred as an apprentice to a ship-chandler, in whose employ he continued until he went to sea, first as a clerk, afterwards as supercargo, and finally as master and supercargo jointly. It was while he was in the chandler's shop that he first manifested his strong bent for mathematics. Every moment that he could snatch from the counter was given to the slate.

He sailed on his first voyage in 1795 as captain's clerk aboard the ship *Henry* of Salem, to the Isle of Bourbon. His second voyage was made as supercargo, on board the *Astraea* of Salem, to Lisbon, Madeira and Manila. In August, 1798, he went in the same ship to Cadiz, thence to the Mediterranean, loaded at Alicant and arrived at Salem in 1799. The fourth and last voyage in the same ship was from Boston to Batavia and Manila. During the trip, Bowditch taught the crew of twelve men the principles of navigation, and every one of these sailors subsequently rose to the rank of captain or chief mate of a ship. He had with him John Hamilton Moore's book on Navigation, then in common use on board our vessels, which he had undertaken to look over for a publisher named Blunt. When he had been engaged upon it for several days, the captain passed by him in the cabin and said, "Well, sir, you seem to put a great many black marks on Johnny Moore." "Yes," replied Bowditch, "and well I may, for he deserves it; his book is nothing but a tissue of errors from beginning to end." Such was the germ of "The New American Practical Navigator"; two revised editions were issued, but still under the name of the original compiler; but in the year 1802 Bowditch published the book under his own name, since he had actually gone through all the calculations in the Tables and corrected so many errors. This work, entitled "The New American Practical Navigator," became the standard authority in the U. S. Navy and has been frequently revised.

The quiet and leisure of the long East India voyages, when the ship was lazily sweeping along under the steady impulse of the trade winds, afforded fine opportunities for mathematical and general studies. It was at this time that he learned French and Spanish, and later he added German and Italian without the aid of an instructor.

In 1806 Bowditch published a chart of the harbors of Salem, Beverly, Marblehead and Manchester, the survey of which had occupied him during the summers of the three preceding years.

His mathematical attainments were by now attracting attention. In June, 1802, his ship lying wind-bound in port, he went out to Cambridge to attend the exercises of Commencement Day at Harvard; while standing in one of the aisles of the church, as the president was announcing the honorary degrees conferred that day, his attention was aroused by hearing his own name called out as Master of Arts. The announcement came wholly as a surprise, it was his first honor, his earliest distinction — kindly meant and timely done — and in after life, amid all the distinctions he received from scientific bodies, there was not one which afforded him half the pleasure of the degree from Harvard.

On leaving the sea, in 1804, Bowditch became president of a marine insurance company in Salem, the duties of which he continued to discharge till the year 1823, when, on the establishment of the Massachusetts Hospital Life Insurance Company in Boston, he was elected president and, removing to that city, he spent there the last fifteen years of his life. In the leisure hours of an active life, he communicated several papers on scientific questions to the American Academy of which he was elected a member in 1799; but the great work, upon which his fame ultimately rests is his copious commentary upon the "*Mécanique Céleste*" of Laplace, of which he made the first entire translation. More than half of the work as published by Bowditch is an original commentary and exposition, which supplies omissions and deficiencies in the older work, fortifies new positions with proofs and gives additional weight to the old ones, while recording subsequent discoveries. The first volume was published in 1829, the second in 1832 and the third in 1834, each volume containing about a thousand quarto pages. The fourth and last volume was nearly completed at the time of his death; during his illness, among other occupations, he employed himself in correcting the sheets of the last volume of his great work. He died in 1838, having completed one thousand pages of the book.

TYCHO BRAHE

Who Would Not Believe the Earth Revolves

ON December 14, 1546, three years after the death of Copernicus, and sixty-three years before Galileo's invention of the telescope, the great Danish astronomer Tycho Brahe was born, of a noble family, at Knudstrup, his father's estate in the south of Sweden, which at that time was a province of Denmark. Tyge—for that was his real name—was the son and heir of a privy councillor who held high offices of state, but at the age of one year the infant was kidnapped by a wealthy, childless uncle, an admiral, who longed for a boy to bring up as his own. Tycho's parents were soon reconciled to the arrangement, and the boy received an excellent education at the universities of Copenhagen and then of Leipzig, in order to qualify for the political career to which his guardian intended to devote him. But Tycho's interests soon turned to the starry heavens. An eclipse of the sun, on August 21, 1560, was the beginning of his astronomical career. He had already dipped into astrology, but the scientific knowledge which could foretell the precise moment of the eclipse impressed him as no less than miraculous. Under every discouragement the boy studied the sky when his tutor was asleep, and by the age of sixteen had arrived at far-reaching conclusions which were soon to revolutionize the science. Kepler, his great successor, has recorded that "the restoration of astronomy by that phœnix of astronomers, Tycho, was first conceived and determined on in the year 1564". His leading idea was an unremitting course of the most accurate possible observations, in order to reveal the nature of planetary motions and the structure of the solar system.

After residence at the universities of Wittenberg and Rostock, which were seething with the revival of science, Tycho settled at Augsburg, where he constructed a huge quadrant, of nineteen feet radius; and after the death of his father, in 1571, he removed to Heridsvad Abbey, near Helsingborg, formerly a monastery, but now the home of an uncle. Experiments in alchemy had begun to distract him when an astounding celestial portent recalled him to a life-long devotion. He was in his twenty-seventh year when, on November 11, 1572, returning from the laboratory to the house for supper, he was aware of an excessively brilliant star in Cassiopeia, where none had been seen before. For eighteen months, as the new star declined in brightness, he continued to study it; and having written an account of it, under the title "*De Nova Stella*", was persuaded at last to publish it, for he was held back by the prejudice that it was improper for a nobleman to write books. The little volume, now very rare, besides astronomical facts, contains much grandiose moralizing in Latin verse, and predictions of "wars, seditions, captivity, and death of princes and destruction of cities, together with dryness and fiery meteors in the air, pestilence, and venomous snakes"!

Improper as it was for a nobleman to turn astronomer and write books, it was worse to marry a peasant girl. Tycho, who was of an exceedingly arrogant and overbearing temper, soon found it desirable to live elsewhere than among his own people. King Frederick II, however, unwilling to lose so rare an ornament to his country, persuaded the astronomer to accept the gift of an island, together with means to build a home and observatory.

So it was on the island of Hveen that Tycho Brahe carried out most of his life's work. Complicated difficulties, due chiefly to his own fault, drove him from the island in 1597. He left Denmark forever and, after an unsettled interval, he found protection and a salary from the German emperor, Rudolph II, who also gave him for a home the royal castle of Benatky, twenty-two miles northeast of Prague. Here Kepler, whose fame was ultimately to be no less than his, joined him in 1600, as one of his several assistants; and in the same year Tycho removed, with his instruments, to the city of Prague. He died on October 24, 1601, and was buried in the Teynkirche in the latter city, having left to Kepler the enormous records of his observations.

Tycho Brahe was indeed "a king among astronomers". His unrelenting mind carried forward the boundaries of the science in every one of its provinces, initiating that deliberate and sanguine campaign of investigation of which no one can foresee the end. Nevertheless, he was a man of his time. He was in the habit, for instance, of casting the horoscopes of his friends, and some of these were fulfilled in detail with astonishing accuracy.

He was impeded by a too literal deference to the authority of the ancients, as

TYCHO BRAHE

well as by a too easy acceptance of popular prejudices, so that, although the great work of Copernicus was famous before he was born, Tycho Brahe maintained to the end that the earth was at rest, the fixed center of the physical universe. His own system (for he rejected the Ptolemaic equally with the Copernican) came to him "as if by inspiration", in 1583. Dr. Dreyer, Brahe's biographer, represents it as follows: "The earth is the center of the universe, and the center of the orbits of the moon and the sun, as well as of the sphere of the fixed stars, which latter revolves round it in twenty-four hours, carrying all the planets with it. The sun is the center of the orbits of the five planets, of which Mercury and Venus move in orbits whose radii are smaller than that of the solar orbit, while the orbits of Mars, Jupiter, and Saturn encircle the earth." Dr. Dreyer remarks that "this system is in reality absolutely identical with the system of Copernicus, and all computations of the places of planets are the same for the two systems", yet the fact that Brahe was kept, by such puerile considerations, from accepting the conclusions of his great predecessor is one of the puzzles of that wayward instrument the human mind.

Tycho Brahe's positive achievements were of vast extent and variety, and coupled with his princely way of life on the island gave him an immense and somewhat mysterious reputation. In the first place, he was a very ingenious inventor and improver of astronomical instruments and methods of observation, owing to his passion for minute accuracy, for before his time observations had been comparatively casual in character. Beginning as a boy with a simple pair of compasses, held out at arm's length, to measure the distances between stars, he elaborated, as the years went on, instruments far more efficient than had been known before, and published in 1598 a folio volume, "*Mechanica*", illustrated by woodcuts of his equatorial armillæ, quadrants, sextants and other apparatus. One of his minor but most useful devices was the invention of "transversals", to increase the minuteness with which a position on the arc of an instrument may be read. This is but one example of countless ingenious contrivances that have come down to us from the island workshops, where many skilled hands carried out the ideas of the master. Even Tycho's books were set up and printed under his own supervision.

Of all his astronomical labors, perhaps his great catalogue of the positions of over one thousand fixed stars was the most ambitious. No considerable advance in mapping the skies had been made since Ptolemy's catalogue, which had been made fourteen centuries before, and was

perhaps little more than a compilation from the yet more ancient observations of Hipparchus. Having determined with the utmost possible accuracy the positions of a few standard stars, Tycho measured the positions of all the others in relation to these; and although his results have, of course, been superseded by the far more accurate and extensive labors of modern observatories, he established a solid basis for astronomical research that was of the greatest value to his successors. In his book on the great comet of 1577, which he boldly entitled "Introduction to the New Astronomy", he not only demonstrated the fact, previously uncertain, that comets are celestial bodies, and not atmospheric phenomena of some kind, but also speculated profoundly, though often erroneously, upon the structure of the heavens. His studies also included determinations of the complex movements of the moon, of the solar parallax, of refraction, and especially of the movements of the planets — the subject which most deeply interested him from boyhood to the day of his death. But the actual determination of the planetary orbits was reserved for his loyal assistant and constant admirer, Kepler.

GIOVANNI DOMENICO CASSINI
The Man Who "Wrote His Name on Saturn"

CASSINI, one of the greatest of the early telescopic observers, and an all-round astronomer of much ability, was born on June 8, 1625, at Perinaldo, near Nice. Having studied under the Jesuits at Genoa, he was appointed, at the age of twenty-five years, professor of astronomy at Bologna, the most illustrious of Italian universities. His great reputation, gained chiefly by his studies of the planets and their satellites, secured for him appointment as the first director of the newly established Observatory of Paris, and in 1673 he was naturalized a French subject. For four generations the family of Cassini succeeded one another in this distinguished office. Most of Cassini's important observations were made in France, though his calculation of the period of Jupiter's rotation and his observations of the transits of the giant planet's satellites, as well as his determinations of the rotation periods of Mars and Venus, belong to his earlier life at Bologna.

Cassini's discoveries were numerous because he worked in a field which was still comparatively new to telescopic research. They include four of Saturn's satellites, only one satellite having been ascribed to this planet before his time; the discovery of the double character of Saturn's rings, the belt being divided by what came to be known as "Cassini's division", and the eighth satellite of Jupiter, known as Iapetus. The Saturnian moons were discovered between 1671 and 1684, Iapetus in 1671, and the division between Saturn's rings in 1675.

But Cassini carried out also many other important works, including a most laborious and accurate chart of the surface of the moon, showing the craters, seas, rills, rays, mountains, etc., as clearly as was possible with the instruments of his time; tables of Jupiter's satellites and their revolutions round the planet; the elaboration of a complete theory of the laws of variation of the moon's axis, approximating very nearly to the values now ascertained; and the completion of the meridional line from Paris to Rousillon. It was chiefly at Cassini's instigation that the famous expedition was sent out to Cayenne, which succeeded in establishing the fact that gravity decreases in value from the poles to the equator, so that the same object is heavier in higher latitudes than it is in lower latitudes. He was one of the earliest observers of the zodiacal light, and also one of the first to measure the sun's parallax. He died on September 11, 1712.

AGNES MARY CLERKE
A Woman Who Could Make Astronomy Plain

AGNES MARY CLERKE was born at Skibbereen, County Cork, Ireland, on February 10, 1842. Her father was the manager of a bank, and from him she inherited her taste for astronomy, which she studied from the age of twelve. Though never conspicuous as a practical astronomer, she obtained such a clear and comprehensive understanding of the subject as gives to

her books, written in a popular, lucid and simple style, making the difficult scientific problems of interest to the general reader, an exceptional value.

Between 1867 and 1877 Miss Clerke and her sister resided in Italy, chiefly in Florence; and during this time her first astronomical essay was written — a paper called "Copernicus in Italy", printed in the *Edinburgh Review*, April, 1877. In that year the family settled in London. In 1888, on the invitation of Sir David Gill, she went to South Africa, and spent three months at the Cape Observatory, where a telescope and a spectroscope were set apart for her use; and during this visit she made considerable observations of various stars, as she did in 1890 from a yacht in the Baltic.

Her most important books, all three of which have become standard works and have run through several editions, are: "A Popular History of Astronomy in the Nineteenth Century" (1885), "The System of the Stars" (1890), and "Problems in Astrophysics" (1903). Other smaller books are: "The Herschels and Modern Astronomy" (1895), "Astronomy" (1898), "Modern Cosmogonies" (1905). She also contributed many papers to the *Observatory Magazine*, and articles and biographies of famous astronomers to the Eleventh Edition of the "Encyclopædia Britannica", notably on the history of astronomy. In 1892 Miss Clerke was awarded the Actonian prize for her work in popularizing astronomy. In 1903 she was elected honorary member of the Royal Astronomical Society. She died at South Kensington on January 20, 1907.

NICOLAUS COPERNICUS

A Modest Pole Who Rediscovered the Earth's Rotation

ARISTARCHUS, the ancient Greek philosopher, had recognized that the daily rotation of the earth, and its orbital journey round the sun, afforded the simplest explanation of the apparent movements of the starry heavens. His pronouncement was, however, rejected by his contemporaries and successors, and the central fact of astronomy lay hidden in oblivion for seventeen centuries, until rediscovered by Niklas Koppernigk, who was born at Thorn, a Prussian town on the Vistula then belonging to Poland, on February 19, 1473.

Copernicus — for we shall keep to the Latin form of his name — was the son of a wealthy merchant in that town, and was instructed in the Latin and Greek languages at home. In 1491, at the age of eighteen, he proceeded to the University of Cracow, where he was taught the Ptolemaic astromony which had so long reigned unquestioned; and in 1496 entered on a long course of various studies at the most famous Italian universities — Bologna, Rome, Padua, Ferrara. He returned to his northern home in 1506, probably with a universal grasp of the knowledge of his time.

All this was, of course, at a period of extraordinary intellectual and spiritual fervor. Almost simultaneously, scholars had discovered the ancient world, and mariners and adventurers the new; and the change which Copernicus experienced from the low, cold, misty plains of the Baltic to sunny and opulent Italy, then at the height of her splendor, would be to him hardly distinguishable from that tremendous historic movement by which the human spirit became more fully aware of the majesty and wealth of its earthly home. Having seen men and cities, and educated with a wide catholicity for which our modern specialized learning is perhaps a poor substitute, Copernicus, Doctor of Canon Law, and appointed a canon of the cathedral at Frauenburg, on the Baltic coast, took up his residence in that town for the rest of his life, and won an enviable reputation as an administrator, judge, physician, and social reformer. With all that side of his life, honorable as it was, we are not here concerned, but we may regret the days when the world's great men were all-round men, and therefore so much the greater.

During the thirty-seven years from his establishment at Frauenburg until his death, on May 24, 1543, Copernicus was absorbed in the problems of astronomy, and, notwithstanding his reticence and modesty, was early known as an authority on that science, so that his opinion was

invited when the reform of the calendar was under review by the Lateran Council in 1514.

He made many astronomical observations, directed chiefly to the more accurate determination of planetary orbits and of eclipses of the sun and moon, but his work lay rather in meditation and calculation than in observation. He became more and more impressed by the intolerable complexity of the movements which the Ptolemaic system inevitably ascribed to the planets, and came to the conclusion that all these incredible complications must be due to some radical error in the way which men sought to understand these orbital motions.

With this problem in his mind, he found references in the works both of Cicero and of Plutarch to an ancient conjecture that the earth itself might be in motion, and in testing that hypothesis found that a daily rotation of the earth on its own axis, and its annual revolution round the sun, were in themselves sufficient to account for the spinning of the heavens round the Poles, and the apparently perverse anomalies in the course of the planets.

"And thus," he wrote in the dedication of his great work, "after long and careful observation, I have found that when the movements of the other planets are referred to the circulation of the earth, and are computed for the revolution of each star, not only do the phenomena necessarily follow therefrom, but the order and magnitude of the stars, and all their orbs, and the heaven itself, are so connected that in no part can anything be transposed without confusion to the rest and to the universe."

Copernicus incorporated his theory in a work, entitled "*De Revolutionibus Orbium Cœlestium*", of which the manuscript was completed in 1530. It was not, however, published until 1543, and Copernicus received the first printed copy on the day of his death. The work was dedicated to the Pope, Paul III, and a cardinal had long urged its publication, but the reluctant author had held it back for years, dreading the popular clamor which his bold speculations were sure to arouse. Its advent was heralded, however, by a short summary of the system, prepared by Copernicus and circulated in manuscript, as well as by a book written by Rheticus, an enthusiastic disciple, and published in 1540.

Dr. Dreyer, the historian of planetary systems, sums up the contribution of Copernicus to knowledge in the following words: "Copernicus not only showed that the assumption of the annual motion of the earth round the sun would explain in a very simple manner the most glaring irregularities in the motions of the planets, but he built up a complete system of astronomy thereon, a system capable of

COPERNICUS'S SYSTEM OF THE UNIVERSE

being further developed as soon as an indefatigable observer had perceived the necessity of cross-examining the heavens in a persevering manner."

The Copernican theory involved far too profound a revolution in man's estimate of his own place in the universe to win early or easy acceptance. Even so great an astronomer as Tycho Brahe rejected it utterly. Yet its audacity and simplicity attracted the attention of every astronomer; the public mind became gradually familiarized with it; and the magnificent work of Kepler, in purging the system of Copernicus from its remaining errors, and in revealing the true laws of the motions of the planets, set the question finally at rest.

The frog-bit, floating on the surface of pond waters, drops buds that sink to the bottom before winter, as seen in the upper picture, where one bud has sunk, another is sinking, and a third remains attached to the plant. In the lower picture is seen a young plant which has developed from a bud that has risen to the surface in spring; on the left is an undeveloped bud.

These photographs and those on pages 1936 and 1937 are by Mr. J. J. Ward

A NEW STUDY OF HEREDITY

Hereditary Resemblances and Hereditary Differences: Complementary Aspects of the Same Thing

AN INTRODUCTORY REVIEW OF TERMS

ALL truth is one, no fact contradicts another fact, and the smallest fact in the world may trip up the most imposing philosophy. Science, therefore, which is constantly trying to ascend from details to principles, from the present to the past and future, and "from the static to the dynamic view of things", is also constantly compelled to descend again to facts, to survey them anew, and add to their number without end. At the present time, for instance, a theory of evolution which was accepted for decades is crumpling into fragments before the contents of a pea-pod. We examine the individual peas, knowing their ancestry; and the great theory of evolution by the natural selection of minute random variations goes by the board. This outline suffices to indicate what is to follow.

The law of death, as we have seen, is one of the laws of life. The passing of the individual means that the species must be maintained by reproduction. The new individual, as a rule, does not resemble its parent perfectly — compare a human father and his baby boy, or an oak and an acorn — the reason being that the young creature undergoes a period of development before it reaches maturity. In this developmental period all sorts of strange things are apt to happen; above all, in the case of the insects, the young butterfly appearing from the egg *not* as a butterfly, but as a wingless, creeping caterpillar. All these stages have to be studied and explained, if possible. But, as we study and explain them, we are impressed, above all, with the chief outstanding fact that the offspring resemble their parents at some stage or other, and that resemblance we call "heredity".

This resemblance is an essential fact of the life-history of species, for there could be no such thing as a species without it. Equally essential is it for any theory of evolution, or for any theory which denies evolution. If we deny evolution and accept special creation, we still avow a belief in heredity, for we declare that existing forms of life are just as they were made by Deity long ages ago. But we do not therein assert that Deity made the forms now alive. We know those were derived from parents, and those from parents, until the "first parents" made by "special creation" are reached. The identity between existing forms and their first parent thus depends upon the most unreserved belief in hereditary resemblance. No evolutionist has such in "heredity", in this sense.

But though he cannot be so entire a believer in heredity as the special creationist, yet he must base all his teaching on the fact of heredity. Certainly he knows that if there were *nothing* but hereditary identity between parents and offspring there could be no evolution, no change of species, no invention of new species. But while he is therefore compelled to assert the fact of hereditary difference, he also believes in hereditary resemblance, for without it species would not exist. If the offspring of human parents were equally likely to be sweet-peas, white rats, or babies, the world of life would not be the world of life we know. But the evolutionist is absolutely dependent upon the details of heredity for any chance of framing a true theory of the *how* of evolution. And that is just the very *crux* of biological controversy at the present time.

Such small, but immeasurably significant details must be hinted at at the start in order to prepare the reader for the discussion of them which must follow, and in which we shall constantly run the danger of not being able to see the wood for the trees. We are going into the wood in a few places, and are going to examine the individual trees, for they, after all, make the wood. But now is our chance to see the wood as a whole; and when we emerge and come out into daylight again we shall take another view of it, from the other side, and with "inside knowledge" which will enable us to perceive as well as to see.

Let us, then, in the first place, be quite sure that we see what this wood is that we are approaching.

The whole of life a unity of which individuals are expressions

It is not a mirage. Only the pitifully ignorant say that there is "nothing in heredity". Our illustration of the peas and rats and babies obviously disposes of them. They may reply that that is not what they meant; but if heredity does not mean that the offspring of human parents are human, rather than leguminous or rodent, nothing means anything. Further, if we are sufficiently unconventional to think before we speak, we shall see that, even if the offspring of a human being were sweet-peas, even if one living species could give rise to another, differing perhaps rather less extremely than people and peas, certain hereditary resemblances would remain. Peas must breathe, they are made of cells which contain living protoplasm, they are born and die, they consume food and excrete waste, and so on.

Living matter everywhere is living matter, life everywhere is life; every living individual is, in origin, a detached portion of one or two previous individuals; and if the nineteenth century proved anything it proved the fundamental identity and continuity of all forms of life. To realize this fully is to see the whole of life as a unity, of which individuals are expressions, somewhat as his "living" works are the expressions of the creative life of a man of genius.

The mere discovery of the cell, of which all living bodies whatsoever are made, establishes this truth once and for all, and to see it fully is to understand that what we call heredity is of the very essence of life. It is not an accident nor anything superposed upon the nature of life, nor one of its evolutionary products. All living bodies are separated parts of some living body of life, born in the remote past, flourishing today, destined to live and to develop for ages to come. And the study of heredity is simply the study of the relation between the generations of which this body of life is composed.

Now, let us come closer to our "wood", and prepare to look at its parts. Already we see something which looks like a serious difficulty, and which has been completely misunderstood until recent years. For while we can no longer question the fact of heredity, which is as fundamental to life as respiration or nutrition, we have also to recognize the fact of difference between parents and offspring. Now, resemblance and difference are opposites, and if hereditary resemblance be a cardinal fact of all life, what are we to say of "hereditary difference"? Can we even employ such an expression?

Ideas once accepted by science but now thrown over

This is well worth spending almost any amount of time upon, for we are just at the beginning of a new epoch in the science of life, the epoch in which, for the first time in the history of knowledge, the relation between hereditary resemblance, often called "heredity", and hereditary difference, often called "variation", is essentially understood. The understanding of it is contained in Mendel's pea-pod; and the phrase "hereditary difference" exactly expresses our new knowledge. The difference is as much hereditary as the resemblance.

Now, we are here throwing over, once and for all, the ideas which science has accepted and worked upon until our own time; we shall not understand what has been achieved unless we realize what those old ideas, still very popular — like so many other dead things — really are.

The supposition that heredity and variation are opposing forces

They sound reasonable, if fairly stated. According to them, heredity is the law that "like begets like". That is as certain as today; and, further, it appeals to our sense of reason. Knowing, as we do, that all individuals are developed from detached portions — detached by budding or splitting or in the form of seed — of other individuals whom we call their parents, the large general resemblance between offspring and parents is felt to be in the nature of things. "Do men gather grapes of thorns, or figs of thistles?" But though "like begets like", it rarely or never begets exactly like; there are differences, small or great, so minute as to require delicate measurement for their detection, or so huge that we call the offspring a "sport" or a "freak".

These differences, considered as a whole, throughout the world of life, are vastly less numerous and important than the resemblances between parents and offspring. We give them the name "variations"; and as they are so much less marked than hereditary resemblance, and seem much less reasonable, we incline to the excusable view that heredity is the law, and the variation is the "accident", or the exception, to the law. Indeed, why not speak of two opposed forces — the force of heredity and the force of variation? This sounds scientific. In the study of physical forces we can measure the onward force of a moving body, and the force which tends to pull it at right angles from its onward path, and then we can achieve what is called the "composition of forces", showing how the planet or the bullet travels in a certain path under the opposing and balancing influence of the two forces which are acting on it. Just so heredity is the force which tends to make an organism go on in the straight line of its species, and variation is the force which acts at a right angle to that; and according to the relative power of the two forces, and the result of their "composition", the new organism will travel along a line which is something between absolute resemblance to, and absolute difference from, the path of the past.

A whole school has been founded on ideas such as these, and has erected wonderful structures, which the growing stream of knowledge has swept away.

For, in fact, the great achievement of our age, in this line of knowledge, is to show that "heredity" and "variation" are not opposed "forces", ranged against each other in the field of life. Heredity is not the law, and variation the exception, or the result of some opposed law. In fact, "heredity" and "variation", likeness and difference, are different and complementary aspects of one thing; and if we are to get any further we must cease to think in terms of likeness and difference, and must content ourselves with the admirable definition, put forward by Professor J. Arthur Thomson a few years ago, that the study of heredity is the study of the organic relation between living generations.

We shall learn, in due course, how this organic relation shows itself, alike in difference and in likeness between the generations, and we shall learn that each of those differences and likenesses has a meaning and a *rationale*, but we must stop thinking in terms of likeness and difference, and trying to arrange all the facts in those categories.

For, if we do, where are we when the offspring differ from the parent but resemble the grandparent? Is that "variation", or is it "heredity"? We commonly reply that that is heredity "skipping a generation", but really our skipping days are over, and we must leave such "explanations" behind us, too. We shall see that, when we start out to observe the organic relation between living generations, not only parents and offspring, but between many successive generations, not only between brothers and sisters, but between cousins even remotely related, then the likenesses and the differences, the "skippings", and "reversions" and "sports", and "atavisms", and all the other things and names that have made such a chaos out of cosmos in our thought hitherto fall into their places, and serve equally and complementarily to illustrate those real laws of heredity at which, until the Mendelian revelation, no one had so much as even guessed.

TRANSFORMATION THROUGH TYPES OF LIFE

The magnified eggs of a butterfly resting on a leaf

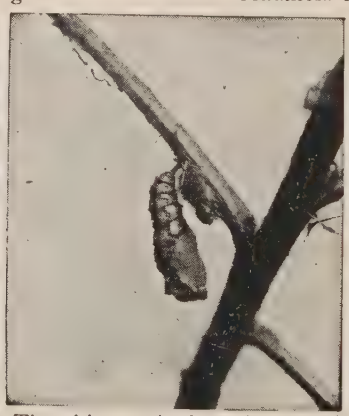
Baby caterpillars feeding on the soft parts of leaves

Caterpillars, three weeks old, swarming about nettles

Caterpillars at the fourth week from their birth, when they are quite full grown

A full-grown caterpillar suspending itself in readiness for its change to a chrysalis

At the half-way stage, when moulting the skin



The skin moulted at the end of four minutes

The chrysalis fully formed, the skin having fallen

AS SEEN IN A PAINTED LADY BUTTERFLY

Chrysalids ready for the butterflies' emergence

A butterfly emerging from its burst chrysalid

The emerged butterfly crawling on to the stem

The beauty of the insect becoming apparent

The gradual extension and drying of the wet wings

The wings under muscular control at the end of an hour

The butterfly, feeling its strength, quickly traveling to the top of the stem

Opening wide its beautiful wings, the perfect insect is ready to fly

Heredity the organic relation between living generations

But we have much to learn before we are ready for the invaluable work of that monkish gardener of Brünn. We have made a beginning, however, and that beginning is contained in the clear and simple idea that what we are about to study is not the "law" that like begets like, nor the "law" that like begets not exactly like, but simply *the organic relation between living generations*. If we study that properly, including two generations if they suffice — as they never do — or twenty if we can trace them, and if we make our genealogical tables not only long but also wide — a cardinal necessity in which records of human genealogy deplorably fail the biologist — we shall find that all the various "laws" of heredity and "exceptions" and contradictions take their place in the complete scheme of which we are now becoming possessed.

This newly perceived truth, that heredity and variation are really one, not only places our science on a firm foundation, but it also frees us from a pseudo-religious theory which, after the fashion which all ages illustrate, sought to demonstrate God in one place at the cost of denying Him everywhere else. This sacrilegious theory asserted that heredity (by which is meant identity between parents and offspring) is "natural", and can be expressed in terms of "natural law", but that variation, the production of the new forms which make for progress, is beyond science to explain, and must be due to the interposition of Deity, ever and anon superimposing new elements upon the effects of the natural law of heredity. The theory, which grew out of the original delusion that heredity and variation were opposites, has the further misfortune of crediting Deity with the deliberate causation of degeneracy as well as of progress, for variations are as often downward as upward, or oftener. So that, on this view, Deity is as much concerned to degrade as to create; and it is, in any case, beneath consideration because it tries to exclude God from the greater part of His own universe.

Heredity and variation complementary aspects of the same thing

Heredity and variation, as we have said, are really one. Neither can be understood without the other, they are two parts or aspects of the same thing, they depend on the same laws. In a word, the science of life has here reached the same stage of understanding which has been discussed elsewhere in this work for the science of energy. The student of physics knows that rest is a special aspect of motion, and that the laws of motion might just as well be called the laws of rest. We no longer think it "natural" that things should rest, and "supernatural" when they move. Nor again shall men ever be so foolish as to think that heredity and variation are opposites, that hereditary likeness is natural, and that variation — which we now see to be no less hereditary — is due to some interference with the natural order.

Differences between individuals that have nothing to do with variation

That is a great gain. The next step is no less important. We have put "heredity" and "variation" together, and have thought of the two terms as simply expressing different aspects of the "organic relation between living generations". And now we must separate, and exclude from any chance of comparison, all those differences between individuals which have nothing to do with heredity or variation, but are due to the different circumstances to which the individuals have been exposed.

An extreme case will serve us best. A man has two legs, his son one. This is a difference between parent and offspring in a most notable and important respect. But the son lost his leg in a railway disaster; and instantly we recognize that that is really an accident of the individual's personal history, and as such has *nothing to do* with our present subject. Now, there are well-known cases where people are *born* with only one leg; and we all see that such a phenomenon comes under our inquiry — for what was the organic relation between parents and offspring if each of them had two legs, and the child has only one?

We have purposely chosen an extreme example, not because we shall ignore the subtler cases, but because a recent fashion, already out of date, has suggested that *all* the characteristics of living creatures are due to heredity, and that there is no distinction between inherent and acquired characters.

Examples of heredity that are true and that are false

There *is* a distinction, obvious in many cases, such as that we have cited; and we must not deny it there because we cannot define it in other cases. To be born with only one leg, or rather, never even prenatally to have had more than one, we call an "inherent character"; and the loss of the leg in the first case we call an "acquired character".

The phrase, than which the terminology of science contains few more inept or more richly productive of fallacy, is passable in some unimportant and extreme instances. Thus, darkness of the skin, technically called "melanism", occurs as a phenomenon of heredity in certain cases. There are moths which are seen to be growing black, from year to year, from generation to generation, and probably birds also. Similarly, there is the darkness of skin of a human being, either a phenomenon of heredity, as in dark-skinned races, or due to years of exposure to a tropical sun, or to tuberculosis of the adrenal glands, producing Addison's disease and bronzing of the skin, or to extensive tattooing, or simply to years of dirt and exposure. The condition of the skin is undoubtedly hereditary in the first case, and an "acquired character" in the others. But what are we to say of it where it is due to Addison's disease, and where the mother had it also, and infected her infant with the microbes of tuberculosis before its birth?

The distinction in heredity that is real, absolute, all-important

Already the reader will see that this subject is simple only in the eyes of those who have not studied it; and that the first results of study, and more than the first, are to increase confusion in one's mind, instead of lessening it. That cannot be helped, however. But if we go slowly, we may go far; and let us lay down the proposition, which greatly helps us, that the relation between the generations is one thing, and the relation of the individual to its surroundings is another. The distinction is real, absolute, all-important.

We must recognize it, to whatever extent life chooses to mingle things so that we lose the thread of them. When we come to trace the relation between the individual and its surroundings, we shall soon find that we cannot follow the threads. We can follow the case of the man whose "acquirement", to use a common abbreviation of "acquired character", is the loss of a leg; or the case of the man whose cutaneous pigmentation is evidently due to tattoo-ink. But what about the loss of the scalp-hair in later life, or in earlier?

Baldness an instance of difficulty in distinguishing true and seeming heredity

It may be due to some parasite, such as favus, which destroys the hair, and that is an acquired character. It may be due to heredity — the bald young man's ancestors were bald. It may be due to senility — the man's skin is undergoing the natural atrophy of old age, and produces less hair. And even though it be hereditary baldness, the hereditary factor may be a particular susceptibility to the growth of certain microbes which attack the roots of the hair and so destroy them. If those microbes are everywhere, parent and offspring will suffer alike and we say, rightly perhaps, the baldness is hereditary. But if the son excludes these microbes, or goes to some part of the world where they do not occur, he keeps his hair, although the father lost his; and we incline to say that "there's nothing in heredity". But does that follow?

Plainly, then, we must not mix up different things, producing a simplicity which has no counterpart in nature, if we are to succeed; and that has been the trouble in this study from the first. Utterly different things have been confounded, the result of numerous factors has been put down to one factor, and all sorts of theories have been invented accordingly which are rubbish.

It needs at least a decade of study to grasp fully the conditions of the problems that are to be solved.

That is why we must go slowly, and be careful with the use of words. For the moment, let us be content with "acquired character", or "acquirement", to stand for the consequences of the relation between the individual and its surroundings — air, light, food, microbes, books and everything else — and let us make up our minds that we shall use the word "variation" *solely* to express those differences between parents and offspring which depend upon the organic relation between parents (and remoter ancestors) and their offspring. This is a most important definition.

Hitherto, and in future, we have used, and will use, the word "variation" only to mean a consequence of the hereditary process, only to mean what depends upon inherent, internal, innate or inborn differences in the material from which have been developed the individuals whom we are studying. Thus, in a word, heredity and variation are the problems of germ-cells.

THE SKIN OF THE NEGRO AND WHITE COMPARED

The darkness of a negro's skin, shown on the left, is caused by pigment in the lower layers and not on the surface, where the color resembles that of the white. The negro's skin is an example of heredity; and melanism in whites, due to years of exposure to a tropical sun, or to disease, is an example of an acquired character.

The darkness of the skin of the negro depends on something that was in the germ-cells whence his body was formed, not upon the addition of pigment to his skin from outside. The first is a matter of heredity with variation — as when negro parents produce a white child, an albino, that has no pigment at all in its skin. The second is a case of the relation between the individual and the environment, which may plant dirt or ink upon or in the white skin, or may whitewash the black skin.

Unfortunately, biology is only just beginning to be rid of the confused use of the word "variation"; and, as we shall see, the confusion has reappeared where we had thought to be rid of it. Terms which the student will still encounter are "blastogenic variations" and "somatogenic variations", the first being those derived from the germ, and the second those derived from the "soma", or body. It is better to drop these terms entirely, for experience has shown the confusion which follows them. Only that which is of germinal origin is to be called a variation.

That is a most satisfactory stage to have reached, for it clears up the kind of paradoxical atmosphere that seems to hang over the assertion that heredity and variation, likeness to parents and unlikeness to parents, are both really the same thing, and are both hereditary. Of course they are, we now see, for they both spring from the character and contents of the germ-cells and the germ-cells *are* the hereditary material — they are the inheritance, and they form the heir. Whatever comes out of them, whether likeness to parents or unlikeness to parents, is demonstrably, necessarily and equally hereditary; and the apparent contradiction of asserting that heredity and variation are different aspects of one thing is seen to be in the nature of the case, and not a contradiction at all. Similarly, one may inherit assets or liabilities. When we come to study Mendelism, and Bateson's "presence or absence theory", we shall see that the likeness or difference between offspring and parent may just exactly depend upon the presence or absence of certain "factors" as the Mendelians call them, in either of the two germ-cells which are the offspring's heritage, and are, indeed, the inheritor.

The many uses of the confusing word "congenital"

In proceeding with this preliminary study of the ideas and vocabulary of our subject, we now light upon the word "congenital". The term will long be employed in medical and other discussions of heredity, but the biologist has ceased to use it. Medical men habitually use the word in from four to six distinct senses. They speak, for instance, of a "congenital" fracture inflicted at birth. They speak of "congenital" club-foot, meaning thereby a deformity produced by some accident before birth. And they also use the word "congenital" to mean innate, inborn or germinal, as in the term "congenital stenosis of the pylorus", where the narrowness of the pyloric end of the stomach is an inborn or germinal variation.

Here is wild confusion enough, in all conscience. But doctors also speak of "congenital heart disease", meaning with perfect indifference either deformities of the heart that are due to innate causes, or deformities due to inflammation caused by the poison of rheumatic fever circulating in the blood of the mother. They also speak of congenital plumbism, where the child is born suffering from lead poisoning; and of "congenital syphilis" or "hereditary syphilis" — of all possible confusions — where the child has been infected with a certain minute parasite of disease; and of "congenital blindness", which is due to an infection acquired at birth.

Words of myriad meaning have no place in a serious scientific discussion

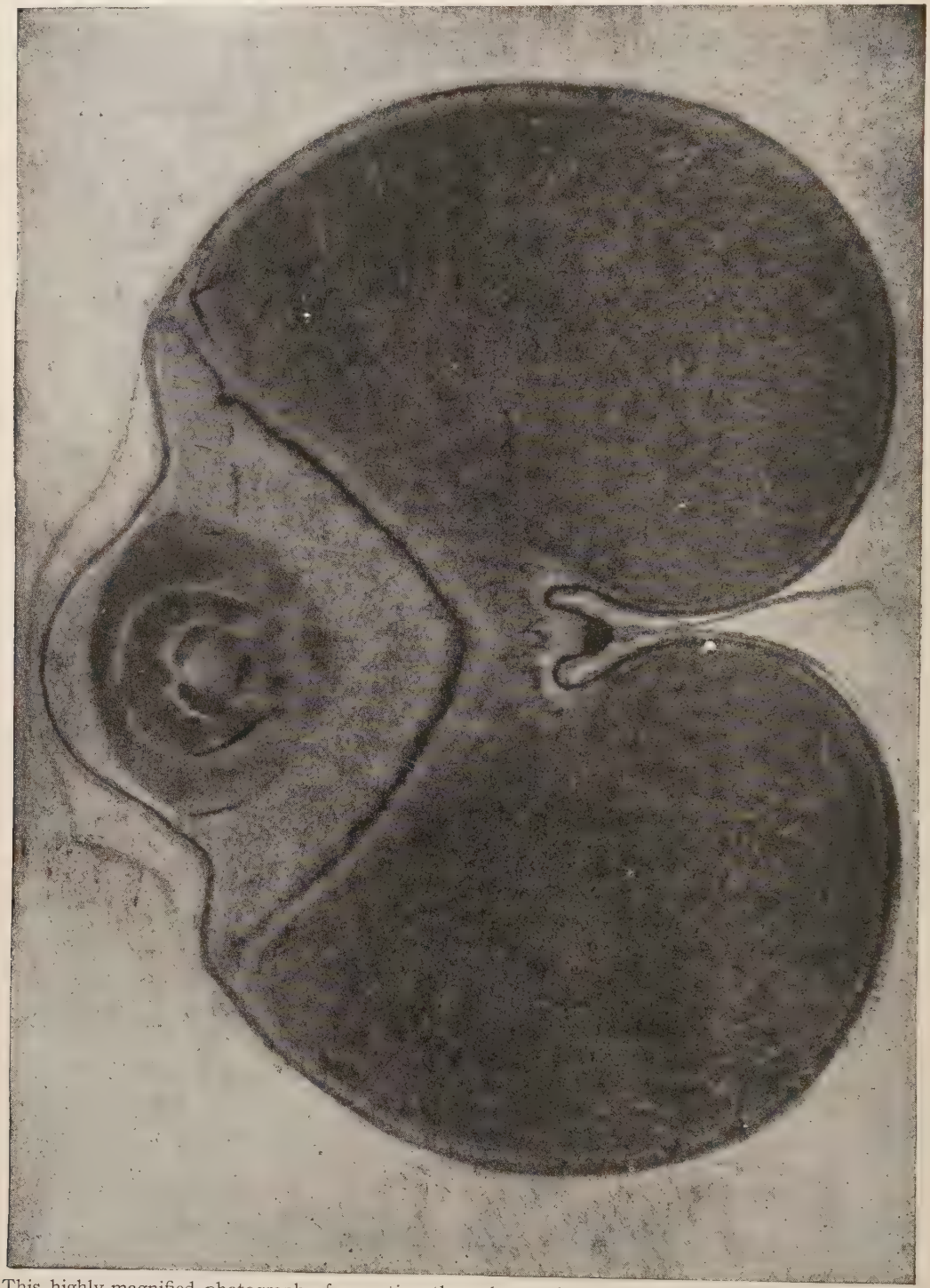
There is no better instance of the danger of words, against which Bacon warned us all at the dawn of modern science. As things stand, the word is much worse than useless, and nothing can be done but to leave it out of our serious discussions altogether. For the foregoing is only half of the objection to it. Whenever the word "congenital" is used, it leads people to suppose that *only* what appears at birth is inborn. And then we suppose that what appears after birth is acquired. As the young creature grows after birth, new characters appear, and we are tempted to say it acquires new characters. But they may be inborn. A man's beard, which does not appear for many years after birth, is yet assuredly inborn or germinal; whereas a deformity present at birth may be due to an accident, and is yet called congenital. Science can make no progress in such a welter of thoughtlessness; and it is time we remembered the caustic remark of Hobbes: "For words are wise men's counters, they do but reckon by them; but they are the money of fools." "Congenital" has too long been the money of the people Hobbes mentions, and it is of no use, even as a counter, to the wise, for how can you count with what never has the same value twice? But how much print and talk and temper would have been saved in the long and acrimonious controversy over heredity if men had been wise enough to use unmistakable and unchangeable counters from the first?

The terms "atavism" and "reversion" do not indicate what really happens

There still remain two words which must also be noted. They are "reversion" and "atavism". When a man takes after his grandfather, we call it a case of "atavism" — heredity "has skipped a generation". Or if the resemblance is to an ancestor more remote, we speak of it as a case of reversion — as, for example, when modern pigeons produce a "blue-rock", or a child has a feeble intelligence and is supposed to be a "throw-back" to some distant ancestor on the father's or mother's side. These words and notions are really obsolete. They sound well, but do not correspond to what really happens. If we are to get into the heart of this most difficult subject, which underlies all the problems of the living world, we must make a clean sweep of most of the old terms and most of our preconceptions. That is what the present chapter has sought to do.

And now if only we remember to forget what we thought we knew, but what was not knowledge, we may proceed to make a beginning with the real knowledge of what we shall learn to call "genetics"—the study of genesis, "the organic relation between living generations".

THE WORLD'S GRANARY IN A GRAIN



This highly magnified photograph of a section through a grain of wheat shows the large proportion that is devoted to the storage of food for the germ, which is on the left, with the cells that will go to form the leaves wrapped round each other in the manner characteristic of the wheat-shoots when they appear above the soil. The diagram on page 1944 indicates the names of the parts to be seen.

This photograph and those on pages 1946, 1947 and 1948 are by Mr. J. J. Ward The others are by Messrs. Hinkins & Son.

PLANTS AS STOREHOUSES

How Plants, by Garnering Rich Foodstuffs
for Their Own Progeny, Feed Mankind

WHERE PLANT-FOOD IS ACCUMULATED

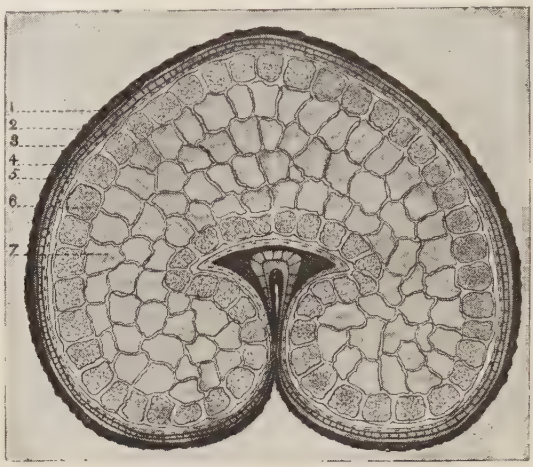
THE search for food must ever be a problem of vital importance to living organisms, but it becomes a more urgent need in the case of plants as compared with animals, inasmuch as the former are without means of locomotion. Their area of food supply is limited; and it therefore is of the more importance that there should be some means devised by which the plant can store up nutrition over and above that required for present needs. Not only is storage of food required for the plant itself, but it is essential to the embryos of the plant, which as compared with animals again, are still more dependent upon some sort of provision for nourishment in their earliest stages.

In our last chapter we saw that in the class of plants to which the bean belonged ample provision is made for the nourishment of the young embryo in the seed-leaves, or cotyledons. These structures play such an important part in the storage of plant food that we must devote further attention to them. As we shall see, they are by no means all like those we have studied in the bean.

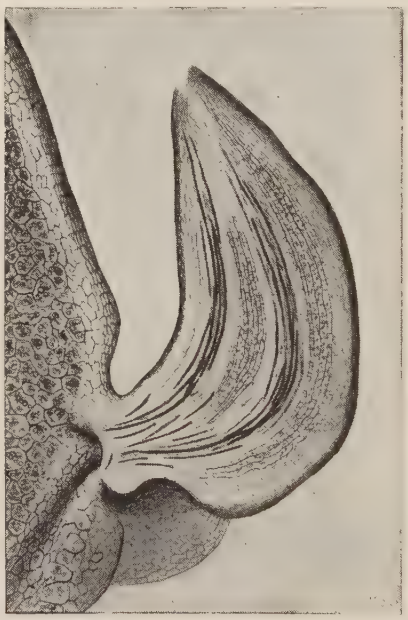
Their function, in the first place, is to provide the primary axis, or embryonic stem, with food. This primary stem, it will be remembered, consisted of the radicle, which grew definitely downwards, and the plumule, growing as definitely upwards. Neither of them at first is capable of getting food for itself, though in the course of time the radicle will throw out root-hairs, and will otherwise develop its capacity as a food-searcher, while the plumule will grow into the stem, and develop leaves that will bear their part also in the general life and nutrition. All this, however, is in the future, and in the meantime food there must be for the growth of these organs. Now, so long as the radicle and the embryonic stem are enveloped within the seed-coat, and, indeed, for some time afterwards, they are functionless, in so far as they cannot absorb inorganic foodstuffs from the soil, and are also utterly incapable of transforming these into organic compounds. Nevertheless, as we saw in studying the processes of nutrition, both organic and inorganic substances are required for growth. Not until the radicle has become a root in the true sense of the term, and not until true green leaves have developed from the stem, can the nourishment of the young plant be said to be independent. Until that stage is reached, life is dependent upon previously stored nutrition; food that has been assimilated and carefully deposited within the seed; food derived from the maternal plant; substances which, as regards their actual nature, are composed of starch, fat and proteids, all carefully guarded for the benefit of the embryo.

The storage chambers are, in most cases, the cotyledons. In their cells this supply of reserve material has been packed away until the needs of the growing embryo have made themselves felt. Without them the radicle and the stem would fail to grow, as can be proved by cutting away the cotyledons, when these two structures die from starvation. Special storehouses besides the cotyledons are sometimes formed within the seed-coat, and these, too, contain similar starches, and fats, and proteids, the whole forming the endosperm.

When the germination begins in such a condition, the two cotyledons are seen to increase in length, and to come into contact with this reserve store of food; and it would appear that their function in this case is a special one in connection with absorption. They stand in the position of the middleman in reference to the consumer. They, in the first instance, take up the stored food elements which have been themselves dissolved in the reserve tissue. This dissolving is also sometimes due to the cotyledons themselves. Then the cotyledons act as distributors, taking away the organic compounds from the storage area. It sometimes happens that only a portion of the cotyledons is enabled to act as an absorber of this food, as is the case in the onion, where the special cells required for this purpose are only developed at the end of the cotyledons. In this plant, after the cotyledon has absorbed the stored-up food by means of its own apex, it leaves the cavity of the seed-coat, and assumes a green character, acting in the same way that an ordinary leaf does. Here we have a bulb which has arranged on its stem a number of thick, fleshy folds, or leaves, lying over each other. The bases of these leaves form the main bulk of the "onion", the leaves thinning out as they reach the stem. After the full growth is over in summer, the green portions wither away, and their inferior parts form a protection for the rest of the bulb.



TRANSVERSE SECTION THROUGH A GRAIN OF WHEAT
1, epicarp; 2, mesocarp; 3, endocarp; 4, testa; 5, seed-coat; 6, cells containing aleurone grains; 7, cells containing starch grains.



LONGITUDINAL SECTION OF THE GROWING EYE OF A POTATO

Should such a bulb be kept until the succeeding year, and then planted again, it forms a new set of roots, produces leaves, and an inflorescence which is familiar to all of us when an onion is going to seed. Now, this second growth is dependent for its food supply upon the nourishment stored away in the bulb scales. All this nourishment is used up when the flowering stem is produced; and when the seeds have become ripe, the plant, having nothing more to live upon, dies. The first onion was an annual; the second one, biennial. Sometimes, however, there is no inflorescence formed, but merely shoots like leaves, which themselves form small bulbs, just as an onion seedling does; and these small bulbs are available for perpetuating the life of the plant after the parent plant has died down. In this case the onion becomes a perennial. This variation in the growth of the onion plant, made possible as it is by the different methods of storage and the variety of storage organs, introduces us to the terms "annuals", "biennials" and "perennials", in connection with plant life, and these must be clearly understood before we proceed further.

An annual plant is one which germinates, grows, and finishes its processes of flowering and fruiting within the limits of one single year, and it dies away if its seeds become ripe. That being the case, it is not surprising that annual plants concentrate their energies on the production of

large quantities of seed. The largest annual plants are found in the castor oil group, and in some of the balsams. Usually the whole season, from spring to autumn, is required for an annual to produce its seed, though some of them, of which the common groundsel is an example, produces seed in a few weeks and may even produce a second and third crop in one season.

Biennial plants are those which, beginning as seedlings in one season, produce during that single season only roots, stem and leaves, but neither flowers or seeds. They then undergo a rest stage during the winter, resuming growth in the following spring, and now develop a stem which in this second season bears both flowers and seeds; and when the latter have reached a condition of ripeness the plant dies. Since the process takes two years, the plant is termed "biennial". The parsnip is an example of this.

Plants requiring more than two years before they produce flowers and seeds, or that live as individuals for a period of more than two years, are termed "perennials".

The question of the annual, biennial and perennial habit of life among plants is very intimately connected with the problem of the storage of nutrition. And if a plant dies down at the end of a summer season, and reappears the following spring as the same individual plant, but with new stems and leaves, there must be some sort of provision for the maintenance of its life during the intervening months. In other words, it must have had some method of storing up sufficient food to keep itself alive. This material is the surplus organic foodstuffs made by the plant, and deposited in one or other structure or part of itself where it can be utilized at some future time. If the plant be an annual, this reserve food is stored up in the seeds alone, where, as we have seen, it is utilized by the next generation in the process of germinating. In the case of wheat and other cereal plants, the seed becomes filled with this reserve store of food, termed the "endosperm". In many other annuals, as in the case of the pea and the bean, the storage is looked after by the cotyledons.

To a certain extent the same thing happens in the case of biennials and perennials; that is to say, in plants of these types there is also a certain amount of reserve surplus food stored up in seeds. But a biennial plant, and also a perennial one, does more than this, because before it comes to the end of the growth of a spring and summer, it has collected and stored away a considerable amount of organic material in different parts of its structure. It is upon this surplus store

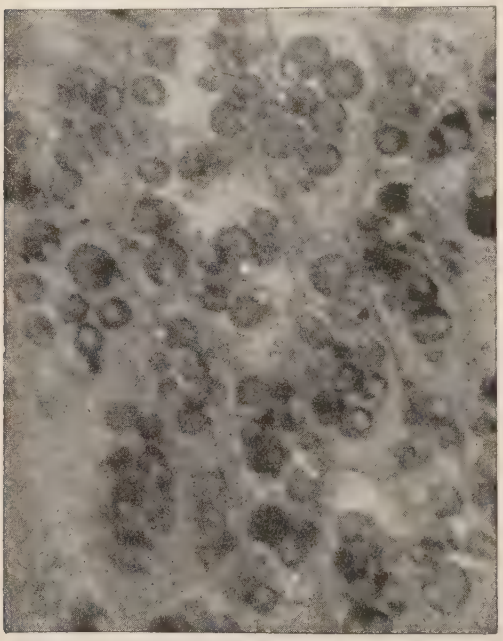
BEAN PLANT AFTER GROWTH OF ROOT AND DEVELOPMENT OF TRUE LEAVES

of food the plant calls for its nourishment in the first part of the following spring, when life and growth become once more obvious to the eye of the least observant.

Other familiar plants offer many examples of various devices for the storage of food. One very common arrangement is to be found in certain roots, such as those of turnips and carrots, where the roots contain the surplus food. We have seen that the onion and similar plants, such as tulips, etc., keep a store of food in

the thick bulb scales. A still more familiar example is the tuberous root of the potato. In hops the storage is in the peculiar roots of the plant, while in most of our trees and shrubs the reserve food is stored during the winter in the cells of the stem itself.

The next question is: What are the actual substances or materials thus stored away as reserve food? They are different organic compounds built up by the activity of the cell protoplasm of the plant, particularly a group of compounds which we know as proteids. Green plants,



PROTEIDS WITHIN THE SEED

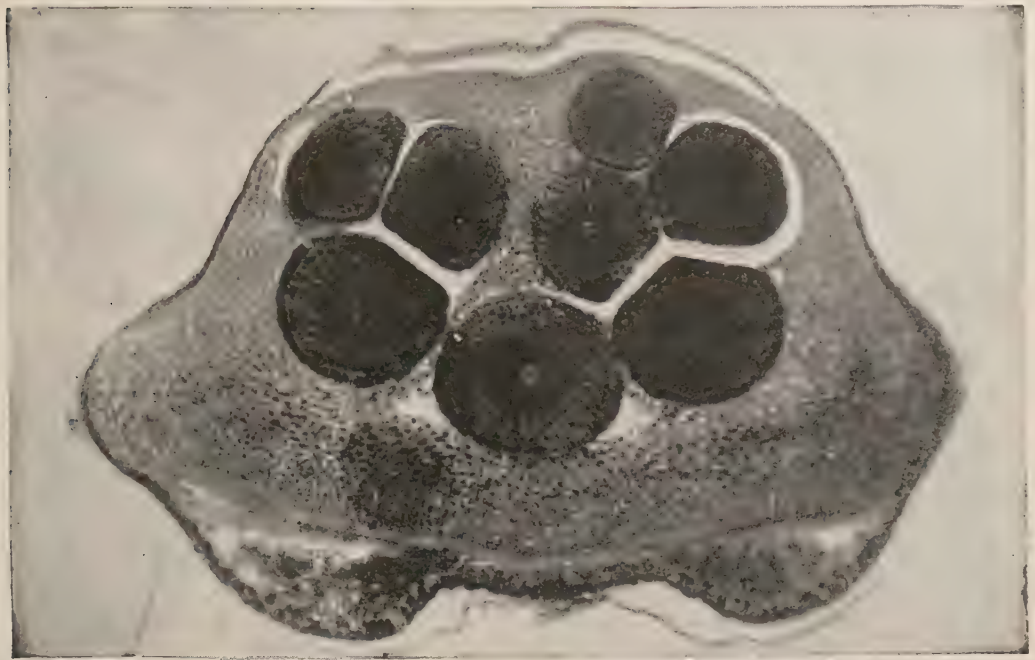
These cells from the endosperm of the castor-oil seed contain aleurone grains, which are proteid crystals combined with an inorganic body termed "globoid". They are here magnified 200,000 times.

while they are growing, build up sugars and other carbohydrates, the nitrogen required for the production of these substances coming from either the atmosphere or the salts in the soil. Some of these sugars and fats are consumed in the early stages of the growth of seeds and bulbs; most of the sugars, fats, and proteids which the plant makes for itself, are used to build up its own protoplasm, and its own cell-walls at the parts where the plant is growing. But if the environment of the plant be satisfactory, and such that active growth is taking place, there is more organic material produced than the plant itself needs for its own immediate use, and this it is which is stored up in the different ways we have mentioned. In most plants these reserves of food are in an insoluble condition, simply because they would require too much space were they to be stored in solution.

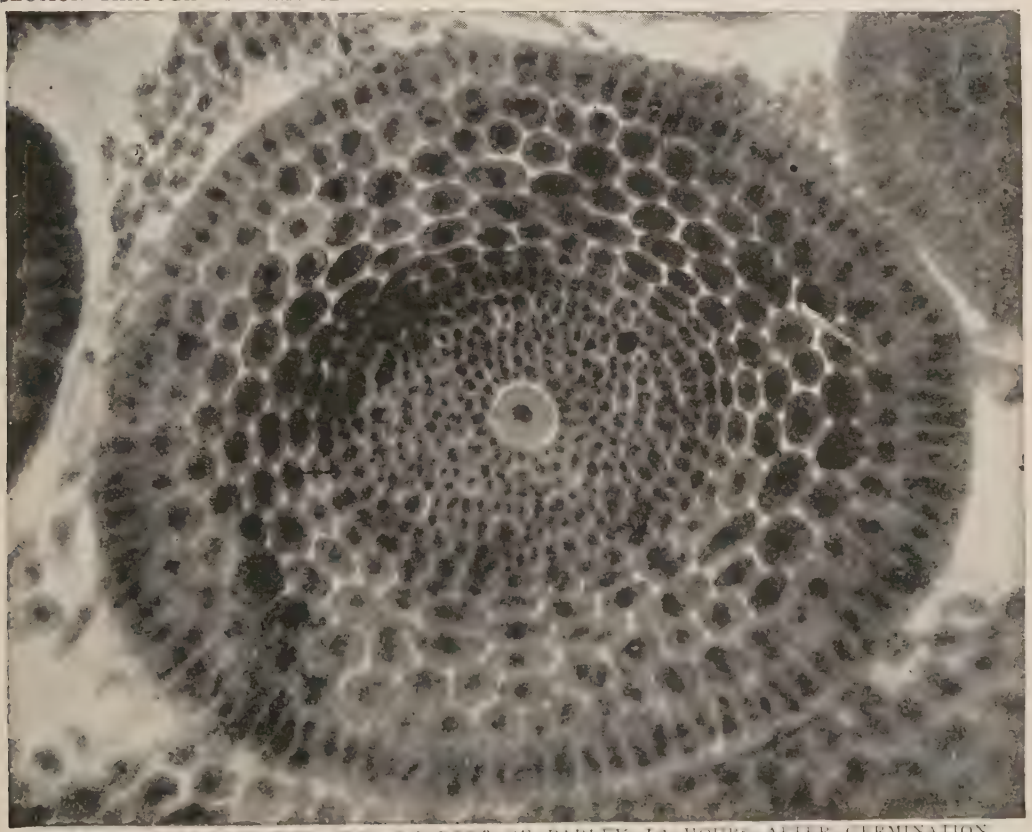
Of all these reserve foods, starch is one of the commonest. It consists of very small grains, made of several layers of the same substance, arranged round a definite point. This starch is in great abundance in roots and tubers, as well as seeds, and it forms no less than from 50 to 70 per cent of cereal grains, while in the case of potatoes from 10 to 30 per cent of the total bulk is composed of starch. The granules of starch are not always of the same kind, and some of them are quite distinctive of the species of plant from which they have come.

Other substances stored for reserve are in the nature of oils and fats, such as are found especially in seeds of cotton and flax. In fact, many seeds are the source of commercial oils. An important point to note in this connection is that the substances stored in their final form are not the same as those originally taken up by the plant. Very complicated chemical processes have taken place in the interval before storage could occur, and particularly in the direction of the solubility and the concentration of those materials. In this final form they cannot escape from the cells which contain them, by the process of osmosis; and this is evidently what has been aimed at. It therefore follows that before they can be utilized by the portions of the plant that require them, they must once more be changed into some soluble form of food which can be carried about in the plant by the usual food channels. This is probably chiefly accomplished as the result of the action of ferments, or enzymes, produced by the protoplasm itself. These ferments are very remarkable substances, particularly in this respect — that they can digest, or transform, an almost unlimited amount of the storage food without themselves becoming used up in the process. One of them, which is termed "diastase", has the

THE INNER WORLD OF A BARLEY SEED



SECTION THROUGH THE RADICLE END OF A SEED OF BARLEY 12 HOURS AFTER GERMINATION



SECTION THROUGH THE PRIMARY ROOT OF BARLEY 12 HOURS AFTER GERMINATION

The upper photograph, magnified [illegible] times, shows the disposition of the cells in the primary or largest root and in the secondary roots. The lower photograph represents the primary root under still higher magnification. The nucleus can be seen in each cell.

power of transforming insoluble carbohydrates into sugars. This ferment acts upon starch, for example, in seeds which are germinating, and is especially prominent in the seeds of cereals. Another form of the same ferment is found in the leaves and shoots of plants; and by means of its action the starch which has been manufactured by the green parts of the plant during the daytime is actually transformed into sugar during the night. This same ferment is abundant in the regions of the eyes of potatoes. Here the starch, which is plentiful, is again transformed into sugar that can be readily carried to the area of growth.

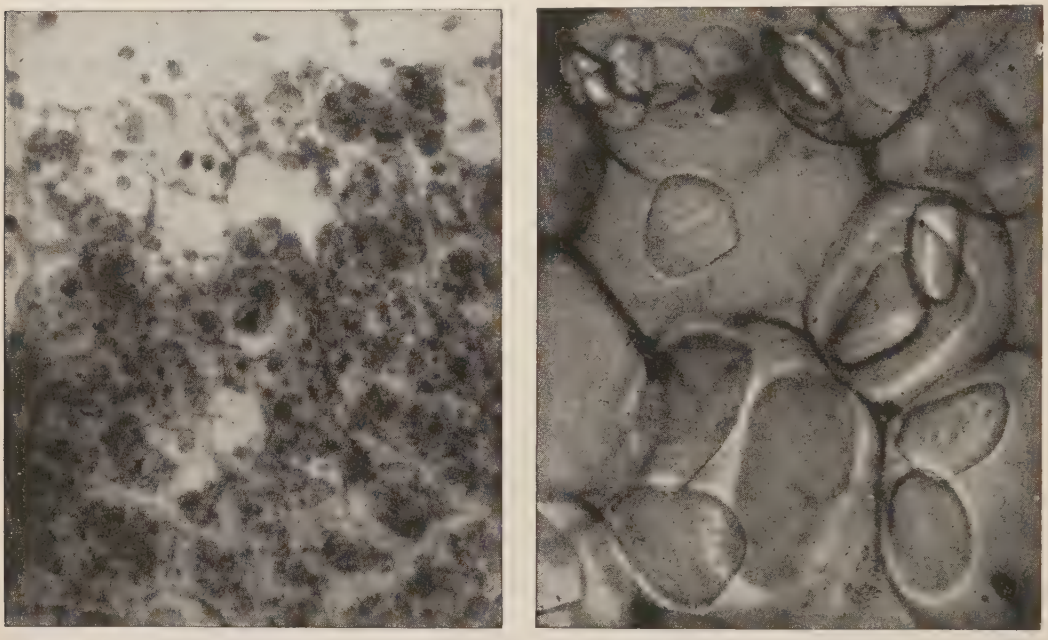
Another ferment which digests these reserve materials in plants is named "cytase", and this is formed in the cotyledons of some seeds, such as peas. Its function appears to be slightly different from that of diastase, inasmuch as it dissolves the cell-walls, wherein the starch is contained, and thus allows diastase to act upon the starch itself.

In some of our common roots much of the organic food material constructed by the leaves in the first growing year is stored up in the root in the form of cane sugar. The carrot is an example of this. The beet is another. Here the reserve is available for use in the following season, but before it can be used it must be acted upon by another ferment which splits up the cane sugar into more readily assimilated forms.

We have mentioned the presence of oil in considerable quantities in seeds such as flax, castor oil, cotton, etc. The ferment that acts upon this form of reserve food, decomposing it, is termed "lipase".

These examples will be sufficient to illustrate the process by which plants keep a store of food available either for their own seeds or for individual subsequent needs. There are other complicated processes, and still other ferments concerned, but the principle in all these cases is the same.

Many of the best examples of the storage of extra nourishment in plants are to be found in some of our most common biennials, such as the parsnip, the carrot, the beet and the turnip, all of these being plants that do not produce seed in their first season's growth, but do so in the second. The immense amount of food stored in these plants gives rise to the fleshy



STARCH GRAINS WITHIN THE CELLS OF THE POTATO TUBER AND ORCHID ROOT
The photograph on the left is magnified some 2000 times, and that on the right some 30,000 times.

roots which are their characteristic, and at the same time gives them their commercial value. Some others, with similar roots, exhibit the same phenomenon on a very much larger scale. One plant (*Ipomœa jalapa*) grown in the United States, a relative of the sweet potato, produces storage organs in the shape of roots that may weigh as much as forty or fifty pounds. Sugar and starch are the main food thus stored. Beet roots contain sufficient sugar to produce a large part of the supply of that article of food for Europe. These biennial plants obviously spend the first year of their lives in accumulating this store of food, to be used later. The stem of the second year, which grows very quickly, depends upon this store for its nourishment; and if the root, so large to begin with, be examined at the end of the second year of growth, when the flowers and the seed have been produced, it will be found very much shrunken and withered, because the food stored up in it has been utilized.

Perennial plants, also, have similar storage organs, excellent examples of which are seen in the common rhubarb and the sweet potato. A number of these plants die down completely above the surface of the ground on the approach of winter, but make abundant growth at the first approach of spring, thanks to their fleshy roots and the food within them.

But it is not only in roots, using that term in its proper sense, that this storage takes place, for we find many plants doing the same thing for the same purpose by means of their underground *stems*. These can be distinguished from roots by, among other things, the presence upon them of small scales, that are really in the nature of leaves. Perhaps the best example of an underground stem of this kind, developed for this purpose, is the common potato, which develops the short, thick, underground stem called the "tuber". A careful examination of the whole of a potato plant will show at once that what we call the potatoes — in other words, the tubers — are not developed on the true roots at all, but are attached to branches of the stem that happen to lie underground. What are known as the "eyes" of the potato are rudimentary buds.

Other examples of underground stems are to be found in many bulbs, some of which have thick scales, like the lily. We have said that most of this storage is for the purpose of carrying these plants over the winter season. But it should be added that that remark applies to our own climatic conditions. In other parts of the world, where there is what is termed the "dry season", as opposed to the "rainy season", the storage of food is required to carry the plant over the dry season, and to enable it to grow more rapidly during the wet season.

LONGITUDINAL SECTION THROUGH A LILY, SHOWING THE BULB SCALES

Perhaps the most extraordinary case, from some points of view, of the phenomenon of food storage in plants is to be found in the sago palm. Here the surplus food is accumulated in the trunk; and in this plant as much as eight hundred pounds in weight of food material in the form of starch may be accumulated. The outer rind of the stem of the palm consists of hard, dense wood, about two inches thick, and inside is an enormous mass of spongy pith which is extracted after the tree is cut down at the age of about fifteen years. This pith, after preparation, becomes the sago used in the household.

We see, therefore, that starch is a common form of food to be stored, not merely in seeds and in roots, as has been already mentioned, but also in the stems of plants.

SOME COMMON AMERICAN SQUIRRELS

RED SQUIRREL

GRAY SQUIRREL

YOUNG FLYING SQUIRRELS

WOODCHUCK — A DEGENERATE SQUIRREL

CHIPMUNK

THE COMMON EASTERN COTTONTAIL

SPERMOPHILES

On the left *Citellus douglassii*, on the right California ground squirrel (*Citellus beecheyi*).

YOUNG VARYING HARE OR "SNOWSHOE RABBIT"

Note large hind foot, shaggy fur and white margin to ears — differing from the cottontail.

Photos A. A. Allen, except spermophiles, supplied by the Bureau of Biological Survey of the U. S. Department of Agriculture.

THE GNAWING ANIMALS

A Vast Order of Prolific Mammals with Which
Man is Compelled to be Constantly at War

THE PROBLEM OF ANIMAL DESTRUCTION

THE rodents, or gnawing animals bring us to the most widely distributed of all the mammalian orders. Embracing close to two thousand species, many of them almost incredibly prolific, the rodents constitute, by sheer weight of numbers, man's most formidable mammalian competitors. A glance at the life of the rodent world fills with despair those who would hope for a fulfilment of the pledge that the lion shall lie down with the lamb. Only by the constant making of war by carnivorous birds and animals upon the rodents, by the unwaning stress of the struggle for existence in which the weakest and less adaptive are mercilessly obliterated, only through the recurrence of those silent, far-reaching tragedies in nature whereby these animals are swept in unnumbered millions to swift destruction, can man maintain his place in life. The inexorable cruelty of nature's laws is, in the last resort, man's paramount defense against these creatures.

It is a strange and grim cycle of alternating prosperity and adversity that maintains the balance of the rodent world. We have among these animals highly organized creatures, far advanced in the scale of evolution — a tiny harvest-mouse is infinitely ahead of the giant kangaroo in this scale — multiplying in favorable seasons like the grain of the skilful husbandman. That increase brings inevitable disaster. Starvation and disease impel a vast migration — to certain death. If the course were varied, if this cruel annihilation did not follow, the rodents would overrun the earth, and leave man starving in a land barren of vegetation.

Consider for a moment the rabbit, the chief pest of Australasia, owing to the introduction of a few couples by one of the early colonists. It has been shown that a pair of Australian rabbits will produce six litters a year, the litter averaging five individuals. As the offspring themselves are sexually mature at the end of six months, this one pair, if none died, might be responsible in five years for a progeny of over 20 million rabbits. The ratio of increase with the rat and the mouse is even more alarming. With all our viruses, our traps, our dogs and cats, it is computed that rats cost the United States alone some fifty millions a year. The animal is useless where even the most primitive sanitary science is practised; it is a robber; it is a conveyer of disease; it flourishes in spite of man.

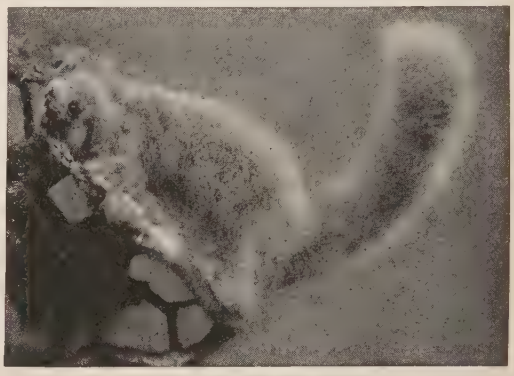
The immense area over which the rodents are spread is a convincing answer to those who still affect to believe that each species originated in the surroundings best fitted for its habitation. Rodents are like weeds: they display extraordinary fertility and persistence in a new land. That is not peculiar to these animals, of course. The red deer of New Zealand have far outgrown the size of the Scottish stock whence they were derived; the domesticated reindeer imported into Labrador rival in size the giant wild reindeer of Siberia; the foxes, carried in an evil hour by a Cumbrian sportsman, for the sake of a hunt or two, to Australia, have become infinitely larger and more powerful and destructive than the original English stock. But the multiplication of rodents in new areas eclipses all other examples of the kind.

The gnawing mammals are an instance of nature's ability to ring the changes upon one design. Certain peculiarities of the rodent's molar teeth recall the dentition of the extinct mastodon, while a peculiarity of the guinea-pig has its parallel in the molar tooth of the modern elephant. The incisors of the rodent are suggested by those of the curious aye-aye, which belongs to the lemur group. These incisors are the paramount feature of interest in the dental equipment of the rodent. With these front teeth it gnaws. It has two in the lower jaw and two in the upper, except in the cases of the hare and rabbit, which are distinguished by the presence of four incisors in the upper jaw.

Another peculiarity of the rodent mouth is that it is departmentalized. The fur of the face is continued into the mouth, which it divides into two distinct sections. The purpose of this is to guard the animal from the danger of getting into its throat any foreign substance which it may be gnawing. The entire mouth of the rodent, both as to this particular and as to the teeth and the specialized shape of the jaw, which admits of the peculiar movement necessary to the mastication of the animal's food, is a beautiful example of adaptation.

The great majority of the rodents have five toes to each foot; and though there is not a thumb or an opposable great toe in

AN ARABIAN JERBOA: THE KANGAROO OF THE RODENTS



JAPANESE FLYING-SQUIRREL WITH PARACHUTE

A rodent's incisor is one of the finest tools in nature. It is a natural chisel, provided on the outer surface with a hard enamel, and on the inner surface with bone which is comparatively soft. As the tooth is used, the inner, softer side readily wears away, always maintaining the sharp edge which the enamel imparts, so exposing a fine cutting surface. The whole tooth grows continuously throughout the animal's life, at a rate commensurate with use, so the rodent, be it beaver or porcupine, hare or mouse, has ever a perfect equipment of tools in its mouth. The chisel is modeled, probably unconsciously, upon the rodent's tooth, with soft iron on one side and hard steel on the other. The ax is another cutting tool of the same derivation — a double chisel, with steel in the middle of the blade and two sections of softer metal, one on each side.

the whole order, the extreme mobility of the forepaws of the beaver, the rat, mouse, squirrel and other animals, strikingly suggests that a rat or a beaver if he had the good fortune to have been blessed with thumbs must have gone very far in the mammalian scale.

We shall have to content ourselves in this chapter with glances at some of the more notable rodents. We shall reach the rats, mice, voles and porcupines in later chapters, while important members of the order have been discussed in a preceding one. We have to note by way of further preface that homes are fashioned by these animals in nearly every available medium. They burrow, they build, they nest, they swim, they even fly. We find the flying animals among the squirrels, which constitute the first family of the order.

The flying-squirrels are more common than is generally supposed. They occur in practically all the Oriental countries, in North America, in northeastern Europe and Asia, in Siberia, in India, in the Malayan countries, and so forth. Of course, the so-called "flying" is only parachuting, performed by means of a fur-covered membrane attached to the fore and hind limbs on each side. In the bat, the hand has become the wing, with the fingers as the supporting rods of the structure. In the flying-squirrels, however, the toes are all free. In all but an African group the parachute is supported by a rod of cartilage produced from the wrist, while the membrane bridges the gap between the hind limbs and the root of the tail, a similar extension joining the forelegs with the neck.

THE SHOWMAN'S "GIANT RAT": A LARGE AQUATIC RODENT, THE COYPU, ON LAND AND IN WATER

In the scale-tailed squirrels, a family composing two distinct genera, and confined to Africa south of the Sahara, we have a squirrel with a parachute of slightly different design. Here the skin is supported by a rod emerging from the elbow instead of from the wrist. Another peculiarity of this squirrel exists in the fact that, extending for some little distance from the root of the tail, the under side of that organ is armed with scales, which afford the animal considerable assistance in climbing.

Whatever their other characteristics, all these flying-squirrels have much the same method of performing their aërial journeys. They cannot fly upward from the ground, nor from a lower to a higher branch. The flight must begin in a downward direction. The impetus gained by this volplane affords the little animal power to rise slightly in the air after the preliminary descent, and also to some extent to change its course when in mid-flight. The distance covered varies with the size of the animal, from the 90 feet and upward of the lesser flying-squirrels, to from 150 to 250 which the greater may achieve.

North America abounds in arboreal as well as ground-keeping squirrels, and they are divisible into many species. Those most common in the eastern half of the country are the red squirrel and the gray squirrel. The former is the smaller and more active — an excitable little rascal which scolds at you as you enter his woodland haunt, or chatters saucily from the orchard fence. His color is rust-red above and white from throat to belly, with a dark stripe along the side. His house is usually a den beneath the roots of some old stump, or in some hollow tree. Here the family dwell in winter, but only the severest weather keeps them shut up. Their stores of nuts, acorns, etc., are laid away in various adjacent nooks and corners, but are seldom buried. The red squirrel, in another of its numerous varieties, inhabits the whole continent except its arctic border and the open plains. In the Rocky Mountain region is found Fremont's squirrel, which is yellow-gray, with a dorsal as well as dark lateral stripes; and on the Pacific Coast lives Douglas's squirrel, whose upper parts are dark gray, with dark dorsal and side stripes, and the lower surface yellow to deep orange. They inhabit the woods and have much the same active and loquacious temperaments and habits as the eastern red squirrels.

The gray squirrel inhabits the eastern half of the United States and Canada, and is decidedly larger than the red one. It is mouse-gray, often showing a yellowish tinge, and has a great feather-shaped tail edged with white. It is very numerous, and is semi-domesticated in villages and public parks all over the country. Its food is varied, and includes many insects and grubs, but it seldom robs birds' nests as does its red brother. It inhabits hollows in trees, or little houses placed there for its accommodation, and often constructs great nests of leaves among the branches of tall trees. In such places it stores food for the winter, and it also buries great numbers of nuts and acorns; but it is abroad all winter, and makes little use of its sav-

A TREASURED FUR-BEARER: THE CHINCHILLA

ings except in the snowy north. In some parts of the country it is regularly shot for the table in the autumn. In the Mississippi Valley and in the Southern States are to be found two somewhat larger squirrels called "fox squirrels" because of the fox-colored tint of their coats. Their habits are similar to those of the northern gray species. All these squirrels develop jet-black races, but there is no proper "black" species. Abert's squirrel and other related species belong to the southwestern border; and Mexico has one or more orange-and-black squirrels of great beauty.

The American flying-squirrels are of two kinds — the common one of the eastern woods, and a much larger and darker form that dwells in Canada and in the western mountain region.

At the other extreme in the squirrel family are the ground-loving prairie dogs and chipmunks, mentioned in the chapter on Animal Home Builders; the numerous species of spermophiles or ground squirrels of western North America; and the large, clumsy woodchucks or marmots which one would scarcely think of calling "squirrels" unless he were familiar with their anatomy. Most of these ground squirrels become serious pests wherever abundant about gardens or grain fields, and it often proves necessary to poison them on a large scale. The U. S. Biological Survey, coöperating with some of the Western States, has succeeded in almost exterminating some of the worst species over large areas.

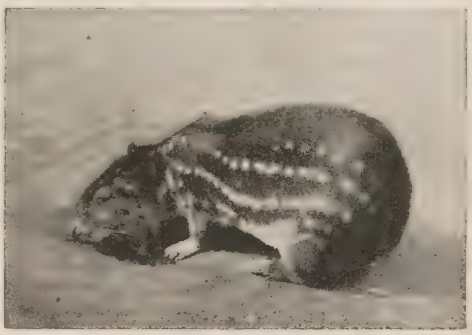
Those of us who are familiar with its engaging manners desire to see the graceful little red squirrel thrive abundantly in our woods, but old legend and suspicion have been verified. In the summer many squirrels may ruin a plantation of young trees by nipping off the tender shoots; and they are rapacious robbers of birds' nests, taking not only the eggs, as has been so long alleged, but actually the callow nestlings. On the other hand, we owe many a noble oak to the acorns hidden in forgotten days by squirrels who meant only to insure a meal against some cold and barren tomorrow.

There are many varieties of squirrels, from the Indian giant, which measures twelve inches from the tip of the nose to the root of the huge, bushy tail, or the huge, woolly flying-squirrel, which is six inches longer, down to the pygmy squirrel, with a body-length of barely more than three inches. Then we get right away from the family to find a relative of a far distant date in the sewellel, which today has not a near relative in the world, and is restricted to the high mountains of eastern Oregon and Washington. It is an animal a foot in length, but with only an inch stump of tail, and it carries a head resembling that of a pug dog. A living relic of a dim past, dwelling in moist ground, and feeding upon plants in the streams near home, it can, by means of its tight-gripping paws, climb the lower branches of trees.

We come next to the jerboas, the kangaroos of the rodent family. Such characterization refers, of course, only to the extraordinarily lengthened hind legs and to the flying leaps with which, when at speed, they progress over the ground. The kangaroo always hops, but the jerboa when moving slowly crawls inelegantly upon all fours, resembling rather the frog or the toad which, when advancing upon its prey or when overcome with fear, waddles upon all four feet. The jerboas are characteristic of the deserts of the Old World, and especially of Africa and southwest Asia. Their diet is, strictly speaking, vegetarian, but some species will eat eggs and even birds; while one, the Afghan species, has mastered the secret of almost complete abstention from water when in a state of freedom, though accepting liquid when captive. Jerboas kept as pets are docile and affectionate, but to confine desert animals fashioned for such boundless freedom seems rather like cooping up some wandering Arab from the tented wild within the limits of a city apartment.

When we come, in a later chapter, to the jumping mice and rats, we shall see how the jerboa-like design has been utilized a second time. Here, however, we pass to the lemming, which is a close ally of the short-tailed field-mouse, found in Scandinavia, in northern Asia and North America. Lemmings resemble the field-mice in appearance and mode of life, dwelling in burrows, but feeding upon grass, reindeer moss, the catkins of the birch and various roots. The chief interest in these animals is, however, associated with the manner of their death, when fate sweeps them in multitudes to destruction. It may be noted in passing that Siberian squirrels are impelled periodically to migrations from which none returns, but the lemming's is the most frequently cited example of the crusade that knows no coming back.

The march is like that of the springboks many times multiplied, and the origin seems to be the same. It is all a matter of food, but the lemming makes its terrible march not yearly, but only once. It is the penalty it pays for excessive prosperity. A colony is started upon the mountain slopes, and speedily attains considerable dimensions. If the weather be severe and the summer not too long, the number of the animals is kept within reasonable bounds. But should spring come early and a year of special abundance follow, the increase in the lemming colony is almost incredible. Disaster may not follow until the next year, or it may come in a long summer following an early spring. The early arrival of summer accelerates the growth of vegetation and with every prospect favoring, the lemmings become millions. The heat of summer scorches up the vegetation, and the overwhelming host of lemmings finds the stock insufficient. Starvation faces them. They do not set out to new grounds and then turn back, after the manner of the springboks.



A SOUTH AMERICAN RODENT: THE PACA

They set out to march to death. The migratory instinct seems to settle upon the lemmings of a vast area all at once. Now, whether all go, or whether some remain laggards, or as guardians of the old home, has not been decided. The lemmings that march out never return; and for two or three years after their departure no lemmings are to be seen in the old quarters. Then a few are observed, and from these a new colony is built up on the old site.

Meanwhile, the army that marches out forms a spectacle of which many men have written with pens dipped in wonder. In innumerable hosts they press forward, millions upon millions of them, all in column, their little feet pressing out a deep path where the myriads pass. All the food encountered by the vastly long column is

THROUGH DEVASTATION TO DEATH

AN UNHEEDED BARRIER IN THE COURSE OF A HOST OF MIGRATING LEMMINGS

eaten by the vanguard; the others throng despairingly on. They will not look at a stream in ordinary times, but now they swim lakes and rivers, cross fjords and arms of seas; they eat their way through haystacks, they crowd streets of towns and villages, they swarm through houses, they press on over mountains. Nothing stays them so long as life lasts. Messengers of death, winged and four-footed, prey upon the stampeding host; waters drown enormous numbers of them; epidemics mow them down as they march. For miles and miles the way is strewn with the bodies of the dead, and the rest struggle on until not a living lemming remains. Such is one of nature's hideous expedients for the reduction of excessive population, and none ever devised could be more effectively complete.

THE GREYHOUND OF RODENTS: THE HARE

THE BANE OF AUSTRALIA: WILD RABBITS

We find an analogous case in the fate of the snowshoe hare (*Lepus americanus*). This animal enjoys cycles of great prosperity — seven fat years in which its numbers are enormously increased. It becomes the staple food of all the North American carnivora, from man to glutton. The Indian, during the year of the snowshoe hare's abundance, forbears to track larger game. Why should he trouble when his squaw can go into the woods and knock on the head as many of these animals as are required to fill her cooking-pot? The flesh-eating animals, too, find food so easy to obtain that wolves and other preying animals leave the larger game comparatively in peace. The larger herbivores, therefore, enjoy a time of rest while the prolific hare is multiplying and filling the mouths of the hungry. And then, after the seventh year, when the wilds are alive with these hares, "the animated wheat of the woodlands", as they are called, come plague and pestilence, and their numbers are reduced almost to vanishing point. The disease passes; the animal is too scarce to make its pursuit profitable; men and animals turn to more considerable game, and the hare is left in peace and health, to increase once more until again he attains numerical proportions sufficient to become the stockpot filler and food of the carnivores.

Take again the strange case of the coypu, a large aquatic rodent, called by showmen "the giant rat", but more nearly resembling the beaver in certain characteristics. The Spaniards regarded it as a species of otter, and called it the *nutria* — which is Spanish for otter. It is by that name that the fur of this animal is known, but it is commonly sold as beaver. There was a great demand for this fur some time ago and the coypu, whose range is limited to the rivers and lakes of South America, became very scarce. A decree was therefore published forbidding their destruction. The consequence was that the coypu changed their habits. Naturally, they burrow into banks and feed upon water weeds, but now, no longer menaced by man, they took to the land, displayed a migratory instinct, and swarmed everywhere in search of food. Thus habit and diet were altered, and the animals throve extremely upon the change. Suddenly a mysterious malady fell upon them, from which they perished and became almost extinct.

Among the most valuable of the fur-bearing rodents are the chinchillas, little burrowing animals distinguished by the kangaroo-like length of their hind limbs, and restricted to the mountainous districts of South America and to the West Indies. The common chinchilla, which supplies the exquisitely soft fur of commerce, has five toes on the fore feet and four on the hind feet, and carries a long, bushy tail; but in the same genus is the short-tailed chinchilla, an animal of greater bodily bulk than the other, and also differentiated in the respect which its name implies. The largest of the chinchillas is Cuvier's, the fur of which, however, though much sought, is far less valuable than that of the true chinchilla.

THE PATAGONIAN CAVY, OR MARA

An interesting group of South American animals follows, beginning with the agouti and the paca. They both resemble extremely large guinea-pigs, the agouti measuring from eighteen to twenty inches from nose to tail, and the paca reaching quite two feet in length. Both are hunted for food, their flesh being considered a delicacy, a particular in which they are distinguished from the cavies. The latter are divided into four species, although the many breeds which have been evolved from the domesticated animal would suggest to the fancier that there must have been infinite natural resources upon which to draw to obtain such varied results. But all our tame varieties are now shown to have descended from one species, Cutler's cavy, which was first domesticated by the Incas in Peru, whence it was carried to Colombia and Ecuador, and brought to Europe soon after the discovery of America. In a state of freedom, cavies frequent marshy districts, where they are sheltered by vegetation, or sandy areas, in which they can burrow. There is one species, however, the Bolivian, which is confined entirely to the higher regions of the Bolivian Andes, where it may be found in large colonies at an elevation of from ten thousand to sixteen thousand feet.

The guinea-pig, like the ferret, prospers more in confinement than when at liberty, both animals proving much more prolific when kept as pets than when dependent for food supply and shelter upon natural conditions. There is one cavy of which the average breeder knows nothing. That is the mara, or Patagonian cavy, a large rodent which at first sight might be mistaken for a member of the hare family or even for a small deer. It attains a length of from two and a half feet to nearly three feet, and stands over a foot in height at the shoulder. The largest of all the rodents is the carpincho, or capybara (also spelled "capivara"). It is a native of all South American rivers on the east side from Colombia to La Plata, and, with a length of about four feet, may weigh nearly 100 pounds. It is a pig-like animal, and is locally known as the "river-hog", but the superior length of its hind limbs causes it when pressed not to run or gallop, but to spring or leap. Although the carpincho damages the bark of young trees, it must have played an important part in keeping watercourses clear, for it feeds chiefly, when not tempted into larceny by cultivated crops, upon aquatic growths which, left to riot unchecked, might eventually choke a river and cause the flooding of the land around.

The picas, hares and rabbits bring us to the end of our list. The picas are small, tailless animals, and the nearest allies of the other animals named, inhabiting northern and central Asia, part of eastern Europe and North America.

EXTERMINATING THE EXTERMINATOR

CORALLING JACK-RABBITS IN CALIFORNIA IN THE DAYS WHEN THEY THREATENED THE DESTRUCTION OF ALL PLANT LIFE

1959

They form huge underground colonies, and the Mongolian specimen, at all events, has the ability to dispense entirely with liquid during the recurrent annual period of drought. Most of the picas frequent the higher mountain ranges; some in the Himalayas flourish at an elevation of as much as 19,000 feet above sea level. The hares and rabbits have the lower levels to themselves, though we have mountain hares as well as polar hares and wood hares and marsh hares and many another species differing in size and color as in habitat.

Hares and rabbits form one genus, but there is much difference between the characteristics and habits of the two. The hare is born clad with hair and with its eyes open; the rabbit at birth is naked and helpless. The common hare has its home absolutely in the open; the rabbit makes such burrows as to become a public danger, even undermining highways.

Much as we read of this plague of rabbits in Australia, none of us can realize what it means—the miles upon miles of pasture ruined by these teeming rodents, the thousands of square miles of land inclosed by "rabbit-proof" wire netting, and the farmers driven to despair as their plans for the extermination of the furry locusts are defeated.

These remarks apply, however, to the European representatives of the species. Properly speaking, America has no rabbits, except in captivity, including the so-called "Belgian hare", which is only a big breed of European rabbit. Our "rabbits"—for the name is too commonly used to be neglected—are really hares, and consist of several species. The common little wood-rabbit or cottontail of the Eastern States remains numerous everywhere, and affords much sport to rural gunners. In so far as its young are born blind and naked, it is a rabbit, but though it often takes refuge in holes in the ground, it never digs them itself. Nor does it have its young in burrows like the true rabbits, but in "forms", usually in thick grass like the hares. The mother cottontail pulls fur from her own body with which to cover the young whenever she leaves them to go on a foraging expedition. In northern New England it is replaced by the larger "varying hare". This animal is extremely numerous all over Canada, and forms the principal reliance for food of the lynx, pekan and other fur-bearing animals, and of the native population of the region. It is the species referred to in this chapter as having alternating periods of scarcity and abundance. In summer it is brown, but when the snowfall begins, it turns white and remains so until spring, when it sheds the white hair and gets a brown coat. On the Arctic coast and islands is found the large polar hare that is white all the year around. Various other species have a more local habitat as, for instance, the bright brown little swamp-rabbit of the Southern States.

The open prairies and plains west of the Mississippi River, and the treeless valleys and basins south and west of the Rocky Mountains and in southern California, possess several species of large hares that are called "jack-rabbits" because of their great, donkey-like ears. These ears are their principal means of guarding against a dangerous surprise by some rapacious enemy, and they are erected on the slightest alarm. Their hind legs are long and strong, and carry the animals away in a series of long leaps with amazing speed. As they find an abundance of grass and herbage for food accessible in winter as well as in summer, they remain abroad at all seasons, making simply a "form" under the shelter of a bush, and sleeping impervious to cold in the thick fur of their coats. This is true, in fact, of all the American rabbits.

The western jack-rabbits have increased greatly in certain districts, and especially in California, as the partial settlement of the country has killed off the coyotes, badgers, hawks and other natural enemies that formerly sufficed to keep their numbers within bounds. It has been necessary in some places, therefore, to organize great "drives" of these rabbits and, after concentrating them in a corral, to kill them by thousands. This reminds one of the vast damage done in Australia by the amazingly rapid spread of European rabbits there.

MAN'S COMPLEX NERVES

The Nervous System in Man and Beast, and the Nature of the Difference Between the Two

MAN'S INFINITE CHOICE IN ACTION

WE have now dealt in succession with the various "systems" which comprise the body of man, and have stated the essential relation between the nervous system, the last to be reached, and all the others — that they are for it and not it for them. When all qualifications have been made, that remains true. The body is a nervous system, evolved and imposed upon circulatory, digestive, respiratory, glandular, bony and other systems. Taken as a whole, the function of all these is to repair, protect, cleanse and ventilate the nervous system, to make it as nearly as possible independent of external circumstances, not at their mercy, though none the less aware of and able to deal with them. But these other systems have another most important function, which is to store up energy for the use of the nervous system. A very great part of the weight and bulk of the body is made of muscles, which are the end organs of motor-nerves, and which contain extraordinary quantities, very easily replenishable, of energy in the form of sugar and allied chemical substances.

Thus the essential reason why the body of man is so complex — all the preceding chapters taken together merely outline the main principles of it — is that the nervous system desires and requires to be as complex as we find it to be. This unimaginable complexity of the nervous system is the supreme fact of the anatomy of man, because of what it makes possible for his conduct, internal and external. It indispensably serves the deeds and the thoughts of man, which are man essentially, nor could any simpler structure serve him thus so well, as we shall see.

But the more complex the nervous system, the more withdrawn from the outside world, and yet the more closely and subtly related and responsive to it, the more does it need by way of support and ventilation and chemical and mechanical appliances and apparatus. Hence the complexity of the body, the amazing number of specialized cells and organs which have been added to it in the course of its development. Each of these new parts is itself alive, and has its own requirements. It reacts on other parts, and they react on it, so that there is no end to the complexity, and yet with all this there remains a no less wonderful simplicity of meaning. For the body, with all its details, exists for the purposes of the life of man, which consists of some kind of action. Let us look at the nervous system afresh from this point of view.

Or, rather, let us first understand what action involves, and how it evolves, in the history of that branch of life of which man is the highest and growing point. And as we trace action, conduct, response, in broad outline, we shall observe how the nervous system appears and evolves correspondingly, requiring more and more of the other arrangements we have already described, until at last we see what the body of man is from the standpoint of a true theory of evolution. We trouble here no longer with the nineteenth century view that the body of man is composed by the accumulation of a vast number of chance variations which persisted and stuck together because they were advantageous. We see clearly that the body is crammed with purpose, and if we would interpret it correctly we must realize what that purpose is.

Purpose is a great word. We do not here mean destiny or purpose in the highest sense. It is quite enough that we should recognize, at this stage, the immediate purpose of the body of man, which is *action*. This is, of course, true of the body of any animal; and it is in the comparison between bodies and nervous systems (when they appear) from the lowest animals up to man that we begin to see why man's actions, conduct, behavior so transcendently excel anything that the lower animals display. Action is for life, or life is for action; and it is idle to pretend that there is any fundamental difference in the bases of conduct, whether we observe them in the amœba or in man — in the one-celled animal that has no nervous system, or in the animal whose nervous system alone contains thousands of millions of cells.

To move towards food and to swallow it is a kind of action common in all its essentials to amœba and to man. The machinery is very different, but the action, the purpose of the action, and the need of the action are precisely the same. The man, with all his complexity, is thus just as simple as the simple amœba so far.

How man is exceedingly different from and yet similar to the lower animals

Therefore, if we are to understand man and the meaning of his nervous system we must trace action upwards in the history of life, and we must try to keep our heads amid the two temptations to which so many of our predecessors have succumbed. They are quite obvious, but none the less perilous, somehow. One is to insist upon the agreement between man and the lower animals, of which there are so many staggering examples like that already furnished, and to conclude, in short, that the difference between man and the lower animals is largely one of degree; not great even at that, but of kind not at all.

The arguments for this view are many and easy and satisfying, and lead to the humorous conclusion of the French writer Beaumarchais that, in some cases, man differs from the lower animals at least in that he eats when he is not hungry and makes love at any time.

The other temptation, just as commonly succumbed to, is to declare that man is so wholly unique and apart that to introduce any comparison between the springs of his conduct and that of the lower animals is to dishonor him and to know nothing of him. The arguments for this view are just as many and satisfactory as for the other. The only condition, in either case, is that one shall know what one wants to see, and shall look only at the evidence in favor of it. But the real truth is the evolutionary one, which we are now beginning to perceive, that man is exceedingly different and exceedingly similar to the lower animals, both in body and in function, which ultimately means behavior.

Unlike either of the half-truths above indicated, which respectively dishonor either man or the lower animals, the whole truth honors him without dishonoring them. We may freely recognize in the nervous system of the dog, for instance, a structure which seems suitable for the display of intelligence, and may unreservedly admit the display of intelligence in the conduct of such an animal, without for a moment regarding Beaumarchais' definition of man as anything but a vulgar falsehood.

Similarity between man and the simplest organisms in procuring energy

Let us see, now, whether these large statements can be justified. The body is a machine for action. The action requires energy and apparatus, and so forth, according to the laws of physics, but the object is simple, and it is realized by the very simplest organisms we know. The amœba is aware, and replies. Its life essentially consists of two processes — first, procuring a supply of energy; and, second, spending it as it will. So, also, does the life of man. Let us see how the evolution of a nervous system and, above all, of man's nervous system, affects these two processes. As regards the first, we shall not trouble, being intent to note its essential character for man as for the amœba. The differences that exist between the two in this respect of "getting", matter little; it is the difference in the respect of "spending" that matters everything.

A MICROPHOTOGRAPH OF ONE OF THE MANY SERVANTS OF THE NERVOUS SYSTEM

The nervous system of man is by far the most complex of all his systems; and in this picture of a spinal ganglion, shown in longitudinal section dotted its scatter, and magnified fifty times, we see a kind of seat of nutrition for the nerve fibers that pass through it from some portion of the body to the spinal cord. The numerous circular ganglion cells, seen in this picture with their little dark nuclei, send fibers to unite in a T-shaped junction with the fibers passing through the ganglion.

The reflex action of the least developed living thing not wholly mechanical

There is no doubt that, until very recently, men of science have underrated amœba and such humble forms of life. But it is still true that, in the main and essentially, their behavior is *reflex*, as we say, and very little more. It is vastly important for our philosophy that there *is* a little more, but it is only very little. For the rest, the action of the amœba is reflex. And here we meet a phrase, "a reflex", or "a reflex action", which is of enormous importance in the study of all forms of animal life and, above all, in the study of the nervous system. The term is not used as strictly as it should be, and different authors often arouse controversy and misunderstanding in consequence. But we mean by it an action which is so constant and rigid and automatic, to all appearances, that it may almost be called a reflection, like, say, the rebound of a billiard-ball from a cushion. If the cushion has "acted", its action is certainly a "pure reflex", constant and automatic.

Now, we shall do well to rid ourselves from the first of the idea, still held by all but the most profound and advanced students, that any reflex action is wholly and truly mechanical, like the "reflex action" of the cushion of a billiard-table. To call it a reflex is only to use a bold metaphor.

Reflex action always involves the psychical fact of sensation

Life is always involved, as we see at once when death supervenes, or the death of the particular nerve-cells involved, if such there be, or when fatigue or intoxication by anæsthetics or otherwise abolishes what we call reflex action. The reflex may be extremely simple, it may be invariable, it may look like the response of a machine, but that is only because life is using machinery for its purpose. The climb from reflex action up to that of the human will is not a climb from unconsciousness to consciousness nor from machinery to life. In the humblest and simplest and oldest reflex action or response of life there is always necessarily involved the psychical fact we call *sensation*.

The law stating "No sensation, no reflex", is absolute. The hair of a living animal, or even of a dead animal, will be pulled, and the skin will return when the pulling ceases. That is elastic response, purely mechanical and independent of sensation. The hair of a living or a dead animal will burn when a match is put to it. That is chemical response, equally independent of sensation. But if the animal be alive, and not poisoned, asleep, or otherwise put out of action, it may *feel* in these cases, and may exhibit a reflex, biting in the direction of the pull, running from the match, or what not.

Sensation the very basis of life

You may also stand beside an automobile, touch a lever, and it will run away; and there we see the mechanical imitation of a reflex action, or the mechanical apparatus of a reflex action. But a real reflex action is a vital act, involving sensation.

Sensation lies at the very basis of all life, above all of the life of man. We shall study it is as a whole before we proceed to study the special forms of apparatus which he possesses for special kinds of sensation. Meanwhile we simply assume sensation for the present purpose. We shall rightly talk of reflex action as automatic, as largely mechanical, as rigid, as involuntary and so forth, but all the while we shall be assuming, because we must, the existence of a psychical fact, which is eternally different in order from anything that those adjectives suggest and which is called sensation.

Now, the amœba feels and responds, though it has no special organs of sensation. It need detain us no further. The next stage that needs description simply shows us a special machinery for feeling and replying, which we call nervous. It is not evolved all at once in this form, but we may pass over its rude sketches, and look at the form which we find in all but very humble animals, and which occurs in millions in the nervous system of man. It is called a reflex arc, or a sensory-motor arc. Not long ago distinctions were drawn between the two; the reflex arc was said to serve a reflex act, in which there was supposed to be no sensation, or only an "unconscious sensation".

Sensation occurs accompanying action in the very humblest of organisms

Such a term is an absurdity; for we know that if any supposed reflex arc not needing sensation be treated so that no sensation can occur, no action will occur. That suffices, and we shall not draw a distinction which does not, and could not, exist.

The typical reflex or sensory-motor arc, such as we find in our own bodies, will consist of a sensory half and a motor half, together with any necessary machinery. A sensory nerve will run from the skin or the eye or anywhere else to some central point, from which a motor nerve will run to a muscle (which is merely the end organ of a nerve); and when a stimulus runs to the center along the sensory nerve and a consequent sensation is felt in the nerve-cell of that sensory nerve, an order will be given by the nerve-cell of the motor nerve so that a movement will occur — the eye, threatened by a blow, or needing the moisture of a tear, will wink, or some such simple reflex action will occur. The anatomical details of the machinery do not much concern us. Few or many nerve-cells may be involved. The movement need not be that of a muscle, for it may be movement in the cells of a gland that secretes saliva or tears or what not — as when our mouth "waters" at an appetizing odor. The sensation may be of any kind, the motor response may be of any kind, but still the act is essentially a reflex or sensory-motor act, performed by means of a nervous arc.

Anatomically the nervous system exists to control the body

If we look at the nervous system of man as a whole, we shall find it hard to believe that there is any particular resemblance between so complicated and various an apparatus and anything so simple as the reflex arc. Yet we can historically trace the evolution of the nervous system from the first to the mature stages of the individual man, and satisfy ourselves that this is, essentially, a number of sensory-motor arcs, no more and no less.

We might imaginably replace all the sensory fibers and cells by one, all the motor fibers and cells by one; and we should have everything that is essential in the nervous system. To it we should require to add a variety of machinery for other purposes, but that would not be essential. If we are to have a heart, and lungs, and so forth, these and other organs will require nervous control. Then, of course, anything so complicated as the body will require much controlling machinery if its parts are to act as a whole, If, therefore, we look at the nervous system anatomically and without any clue, we shall think of it as existing in relation to the rest of the body. We shall observe the nerves running to and from all parts, and we shall insist that the nervous system exists to control and coördinate the whole, to supervise the nutrition of the various organs and keep them in touch with one another.

Now, it is true that the nervous system does all these things, and many more; and it has often been described in these terms, especially by the physiologists, who unravel its relations in the body and the multiplicity of its functions.

The system that exists to converse with the outer world — to feel and reply

Yet so to describe it is to miss the whole point. The nervous system is essentially a sensory-motor or reflex apparatus — with modifications, as we shall see — which exists for conversing with the outside world. It is required to feel, to perceive, to remember, to consider, to reconsider, to ignore, to refuse, to delay, but finally, and in the upshot, to reply — even by not replying. The natural sequence is to feel and to reply. The other terms we have inserted are very important, and explain why the nervous system is really so complicated. But, however many terms and stages and varieties of psychical action we interpose between sensation and response, these are the two essential terms.

And, as a matter of fact, simple acts, involving only these two terms, are constantly being performed by the nervous system of man, just as in the humblest kinds of nervous apparatus that are known. The sensory stimuli, as they are called, may proceed from the outer world, or from

the inner outer world, which is the rest of the body — outside the nervous system, but not outermost. The replies may involve only some act in the body (which is, so to speak,

THE CEREBRO-SPINAL NERVOUS SYSTEM OF MAN

the immediate environment of the nervous system), or may involve some act upon the really external world. But the act is essentially reflex or sensory-motor. We could not maintain our lives for more than a few seconds if these reflexes were not constantly at work. *We* are not aware of them, and from *our* point of view we may call them "unconscious" or "automatic" or what not, but some of our nerve-cells are certainly aware of them, as we should realize only too well if those nerve-cells failed in their duty. The problem of drawing great distinction between such of our nerve-cells and ourselves is too difficult for the present and may fortunately be deferred.

The almost infinite activity of the nervous system — conscious and unconscious

The fact remains that the nervous system, alike during sleep and waking, attention and inattention, conscious activity or repose, without intermission from its first prenatal activity until death, is always performing an almost infinite variety of reflex actions without our conscious assistance — which in many cases would be disastrous, and in many others is actually impossible. We have said *almost* infinite, and the qualification is necessary. When sensory-motor arcs are to be numbered by millions, and when almost any sensory half may be combined with almost any motor half, obviously the number of actions is enormous, but it is neither infinite nor indefinite. All these actions are anatomically conditioned. They depend upon the machinery that exists; and though that machinery is very adaptable, it has its limits. It is not until we reach the highest and latest part of the nervous system that we shall reach the possibilities of the infinite.

We shall see, in due course, how this machinery becomes developed in man, so that he is capable not only of complicated actions but also of delay and reflection and invention and introspection. But no psychology, scientific or mystic, can obscure the truth which modern study of the nervous system and of man as a whole so clearly teaches — that the nervous system is sensory-motor, made of action. All sound systems of thought, and even of ethics and religion, have preached this truth.

Stoicism may have denied it, but stoicism has always led to its own destruction, as such a suicidal doctrine should. The other

systems have taught that man must feel and must act, that the highest type of man is he who feels deepest and acts best, that merely to feel and not to act is contemptible or dangerous. It is not good to cultivate sensation for the sake of sensation, emotion for the sake of emotion, or art for art's sake. These things exist, and have their ultimate justification in conduct. Tragedy, as Aristotle said, should purge the soul with pity and terror, so that its deeds are fairer thereafter — not that we may say "How thrilling!" and go away with our conduct as selfish and pitiless and proud as ever.

The biological theory no less clear in its teaching than the ethical

Such, very briefly, is the ethical teaching of this theory of the nervous system. Its biological teaching is no less clear. Life is something that tries to act on inert matter, and achieve a purpose of its own. This it does in plants that have no nervous system, in animals that have none, and in those that have. It is just the same in man. His nervous system is simply the finest apparatus of the kind hitherto evolved. Our problem is to state its special qualities without losing hold of the anatomical facts. It has all the reflex possibilities, in the first place. Its many sensory-motor arcs are so evolved that the nervous system is capable of feeling and of responding automatically in a vast variety of ways. In the spinal cord and the lower part of the brain of man we find a large number of "nerve centers", each of which is a group of cells that may be "got at" by a variety of sensory paths — from the eye, the skin, the stomach, the ear and so on. These motor mechanisms, which we have not constructed for ourselves, are at our disposal. They wait only for a signal to release, or set going, the corresponding action. Thus we strike or cry or laugh or flinch or walk or breathe or grasp, etc., by setting these prepared nervous mechanisms in motion, or by letting them go. In ourselves their number and variety and their modifiability and adaptability are unique.

But, as we shall see more clearly when we come to study the will, this part of the nervous system constitutes only one-half its excellence in ourselves. Above — literally above, when we stand in the "erect attitude" — this unrivaled assemblage of sensory-motor mechanisms is a newer, subtler apparatus which is the machinery of the will, and it is will that determines what use the prepared mechanisms beneath it shall be put to. Indeed, the will is quite capable of manufacturing new mechanisms by modifying the old ones, and re-piecing them so that we learn and acquire all sorts of habits, good, bad and indifferent. Short of that, the will is concerned either to choose the particular mechanism it will employ, or to combine them for special purposes; and it can decide at what moment it will release the machinery. Many of our acts are thus voluntarily delayed reflexes; we did not strike our enemy when we might, but we "get back" at him later. And thus the will of an animal, and preëminently the will of man, "is the more effective and the more intense, the greater the number of mechanisms it can choose from, the more complicated the switchboard on which all the motor paths cross, or, in other words, the more developed its brain. Thus, the progress of the nervous system assures to the act increasing precision, increasing variety, increasing efficiency, and independence. The organism behaves more and more like a machine for action, which reconstructs itself entirely for every new act, as if it were made of rubber and could, at any moment, change the shape of all its parts."

Man's infinite choice in action through complexity of his nervous development

This, we observe, the amœba itself can do, but man displays this fundamental property of animal life in almost infinitely — perhaps in infinitely — higher degree. In him the power of choice is unique; and that is another way of saying that in him consciousness reaches its highest point.

Consciousness appears the more when creation and choice (which are closely allied) become possible; it lies almost dormant when life is condemned to automatism, and we are not ourselves conscious of our automatic acts, even though nerve-cells somewhere must have felt for their performance.

Choice and consciousness at their highest in us, and in us at our highest, are proportional to the complexity of the switchboard on which the paths called sensory and the paths called motor intersect, or the switchboard from which they can be controlled and recombined. That switchboard is the human brain, the characteristic organ of man, unique in its development in him.

But before we try to estimate the distinctive property of this "switchboard", let us be sure that we appreciate the importance of the machinery it controls. We cannot do so without a few preliminary words on the great subject of instinct. Perhaps the most serious criticism that can be passed by the biologist upon Bergson's estimate of human psychology is that he underrates the importance of instinct. We must allude to that point here because of the interpretation of instinct which we owe to Bergson's predecessor, Spencer.

The undervaluing by Bergson of concealed reflex action in man

The argument of our present chapter is that, no matter whether we look at the nervous system with the microscope, or whether we observe its mode of action, we are compelled to recognize in it a reflex or sensory-motor machine. We have further seen that reflexes may be put together, coördinated, compounded for the performance of acts that remain essentially reflex, but may yet be so complicated and prolonged through successive stages that their essential character is almost hidden.

Now, such acts are, in fact, just those which we call instinctive, and hence Spencer taught us to look upon an instinctive action as a "compound reflex action."

Nothing in Bergson's argument really excludes this view that, considered from the evolutionary aspect, as also considered anatomically, an instinct is a compound reflex. His description and interpretation of the nervous system includes such an explanation of the physical aspect of instinct. But, as we shall see later, Bergson pays little heed to instinct in man, chiefly because of his now celebrated argument, discussed in another section of this work, that instinct and intelligence are fundamentally distinct, and have run along different lines of evolution, instinct culminating in the social insects, and intelligence in man. All that must be granted, and is a great contribution to thought.

The inadequate reverence paid by scientists to the instinct retained by man

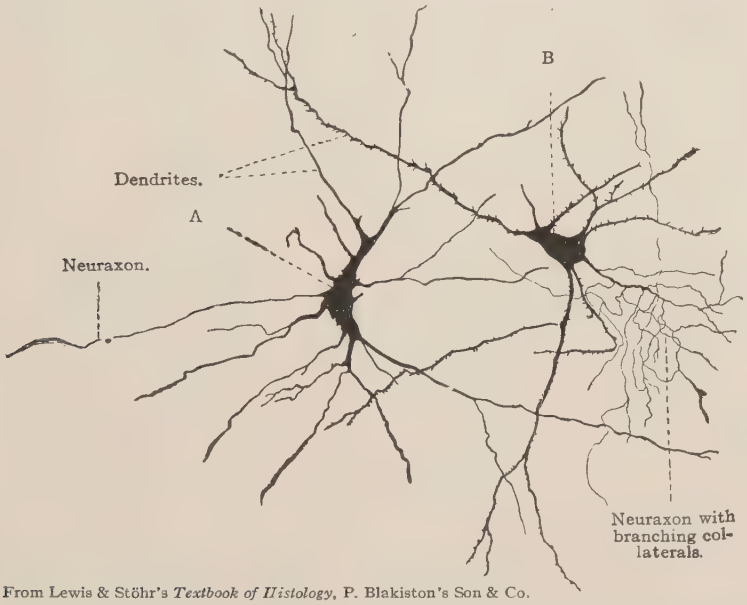
Bergson also argues that a certain portion of instinct, derived from the original powers of unevolved life, remains in the vertebrates and man, just as traces of intelligence may be found in the insects. But it is possible that if Bergson should study the subsequent work of Dr. William McDougall, which must later be discussed at length, he would modify the argument in his "Creative Evolution" to the extent of admitting much more of instinct in man.

For it can no longer be doubted that human psychology has vastly underrated the importance of instinct in man, so much so as almost to admit the sexual instinct and no more, which is truly absurd and has popularly led to very inadequate reverence for instinct in general.

The fact is that we may grant Bergson all he says about intelligence in man, and yet may allow man far more in the way of instinctive endowment than used to be supposed. The intelligence, and the highest parts of the brain, are not therefore of less account. The contrary is the truth. They are of more account because, according to Bergson's own argument, they have so many and potent and various motor mechanisms, essentially instinctive, to combine and control and choose among. As we shall show later, to deny these instincts is to leave the master of the house with no servants, and the will "free", indeed, but impotent. And the truth perceived by Herbert Spencer remains, that an instinct is essentially a compound reflex action. We shall see later that, as Dr. McDougall has shown, the action also has a side of *feeling*, and that this feeling, which we call emotion and which is the inner side of the instinctive act, has been hitherto misunderstood for lack of this simple interpretation.

But though the earlier evolutionists missed that, they were right when, through Spencer, they saw the evolution of instinctive from reflex or sensory-motor action. Only let us remember that instinct has its side of *feeling*, and we shall not run away with the too popular view that instinct is *simply* automatic, and that animals are therefore *automata*, as Descartes supposed and treated as such. That is a stupid view, and anti-evolutionary in the extreme, leaving the *psyche* of man without any natural origin.

in the ape, the brain is made to choose among the various motor mechanisms, essentially sensory-motor arcs, over which it presides. But the evident fact of man is that he can learn to do anything, as is finally evidenced by the fact that he can make any kind of object, including any kind of machinery or device, an engine or a book — which is a sort of engine, too. Hence the brain of man alone can set up an infinite number of mechanisms, so that its choice as to their employment is infinite, too. Only of a brain which can create machines outside the body could



From Lewis & Stöhr's *Textbook of Histology*, P. Blakiston's Son & Co.

TWO NERVE-CELLS OF THE CENTRAL NERVOUS SYSTEM (Magnified 200 times.)

A, cell of Deiter's type, having a neuraxon ending at a considerable distance from the cell body; *B*, cell of Golgi's type, having a neuraxon with many branches ending near the cell body.

Yet, though the continuity between man and the lower animals along the vertebrate line is real, and though the nervous system of man is essentially a group of sensory-motor arcs for action, yet it does overwhelmingly transcend all its predecessors. The brain of man is so large that the quantity of choice and of consciousness which can be displayed through it is unique. But that is not all.

It really looks as if the brain in man had reached a point of capacity which causes it to differ in more than degree from its nearest rivals. Take the highest ape, and we find that, though the creature is intelligent and can learn, its powers and learning are strictly limited. In man, as this be said. The difference, therefore, between man and his nearest rivals is the difference between the limited and the unlimited, the closed and the open. It has become a difference not merely of degree but also of kind.

In reaching that great conclusion to the argument which began with the simple reflexes of any living being, we have also reached a fresh beginning.

We have come to the human at last, as distinguished from what is common to man and to many other creatures. The brain holds the key to all that shall follow; and this supreme organ of all life must next engage such capacities as it displays in us who write and read.

MILLIONS OF STEAM JETS ALWAYS IN ACTIVE OPERATION

From *The National Geographic Magazine*. Copyright, 1920

THE VALLEY OF TEN THOUSAND SMOKES

This picture of one of the greatest wonders of the world was taken by the National Geographic Society's Expedition to Mount Katmai, which discovered the Valley of Ten Thousand Smokes. It is taken at the entrance to the valley, which is more than seventeen miles in length. No complete view from any one vantage point is possible, for so dense is the smoke that everything beyond five miles in any direction is hidden by an impenetrable white pall.

FUTURE SOURCES OF POWER

An Inquiry as to Amount of Energy
of the Universe that Man May Exploit

MECHANICAL DEVICES AND MOTIVE POWER

GEOLOGISTS tell us that in time, millions of years, though, it may be from the present, the earth will be a cold and frozen planet on which life will be impossible. Although the Eskimo lives in a temperature much lower than zero, the cold to which he is subjected is as nothing compared to that of interstellar space, which is far below the point at which life can be sustained. But even if life were possible on such an earth, it is not pleasant to contemplate the state of civilization which could exist under such conditions. City life, as we now know it, would be impossible. When a temperature of zero is sufficient to make the generation of steam in our railroad locomotives so difficult that time-tables become mere scraps of paper, what would happen to our mighty power generating stations of the present day at temperatures so much lower, even if coal and oil were inexhaustible?

And here is the point which causes serious reflection, for the geologists also tell us that our present supplies of coal in sight will be exhausted within a time variously estimated by different scientists at from 300 to 5400 years. At present mechanical energy is cheaper than animal because of the discovery and exploitation of vast coal, peat and oil fields, but we are drawing on these supplies with ever greater and greater demands and the steam and internal combustion engine are already threatening to deplete these stores to an alarming extent. Coal has been used for only about 150 years and oil for an even shorter period, and yet we are beginning to consider the time when these supplies will be entirely exhausted. It is estimated that 60 per cent of the fuel now burned could be saved by economical use, but unless new sources of supply are found, it may be that our present era will be simply a dazzling interlude between the dark ages of the past and the dark age of the future.

The difficulties of the coming generations, facing depletion and even complete exhaustion of the now common sources of light, heat and power, will be many. Man cannot create the real wealth of the world. This wealth, which consists mainly of nature's stores of fuel energy, has required millions of years for its creation. All man can do is to find the treasure, and then devise an ingenious method of using it to his advantage. Without his ingenuity the treasure is valueless. At the present rapid rate of consumption of our fuel resources, our descendants, regardless of their greater scientific knowledge and industrial skill, may be hopelessly poverty-stricken, in spite of their inheritance from us of the knowledge of the so-called "mechanical powers" and similar devices in electricity and chemistry. The industrial development of the modern era is due to our intelligent use of the six mechanical powers: the lever, the inclined plane, the wedge, the wheel and axle, and the screw. Combining these we have evolved the marvelous machines that have enabled us to exploit the immense stores of natural energy in our coal mines and oil fields.

ADAPTATIONS OF THE INCLINED PLANE

A SIMPLE PRINCIPLE IN APPLYING POWER SHOWN IN TWENTY DIFFERENT WAYS

TWENTY WAYS OF USING THE LEVER

The lever is one of the oldest and simplest mechanical devices, yet one of the most important. It enters into every machine and engine, and we cannot talk or walk or eat without using it. There are three orders of levers, as shown here, but every lever must have a rigid rod or frame, straight, as in a crowbar, or bent, as in pincers, and this must rest at some point on a pivot, called the fulcrum. Then any weight or force working at one point in the rod can always be overcome by force applied at another point. In the three orders the positions of fulcrum, weight, and power are different. On this page are examples of each form of lever, and some double levers, such as scissors and pincers.

Exploitation, however, is not creation. One word more in connection with the mechanical powers. Many people undoubtedly are under the impression that the lever, inclined plane, etc. add to our energy resources because with them we can accomplish tasks otherwise impossible. But the definition of energy, "capacity for doing work", shows that the lever is not a source of energy, but simply a means of utilizing energy in a more convenient manner. Work is a measure of energy, and work in English units is measured in foot-pounds. If a man moves one end of a lever a distance of two feet while pushing with a force of 100 pounds, he does 200 foot-pounds of work. At the other end of the lever there can be obtained only 200 foot-pounds of work. This may be 200 pounds moved one foot, or 400 pounds moved half a foot, or 2000 pounds moved one-tenth of a foot, but the product of the weight and the distance moved can be only 200 foot-pounds.

All known machines of man's invention require work to overcome frictional and other resistances. The lever, balanced on a knife edge, is the only mechanical power which gives back practically all of the work done on it. The screw-jack, by which a man may lift an automobile, is another example of a small force applied *to* the mechanism and a large force exerted *by* the mechanism. The man's hand at the end of the bar applies a small force and moves many feet in one turn, while the automobile, which weighs perhaps two tons, is lifted only a short distance. Friction in a screw-jack is a fairly large item, hence the force exerted by the man, multiplied by the distance his hand moves, is much larger than the product of force exerted by the jack and the distance the object is lifted. That is, the work done *by* the jack is less than that done by the man *on* the jack.

No machine has yet been devised which gives out more work than is put into it and none ever will be despite the deluded unfortunates who waste their time and money on perpetual motion machines. No machine, furthermore, will give out as *much* work as is put in, for we always have to contend with the loss by friction of the bearing surfaces; hence, the net work to be taken from a machine will be that put in less that required to overcome the resistances of driving it. At best a perpetual motion machine would be merely a curiosity, a perfect machine which gives back as much work as is put into it, no loss having taken place in the machine. By putting the work done by the machine back into itself it would run forever, *provided* the materials of which it was made did not wear out. But, assuming the machine to be everlasting, if we should try to drive an electric generator by the machine, the latter would promptly stop because we should be attempting to get more work out of it than it had put into itself.

The electric transformer is analogous to the lever. By applying a small current under a high voltage to one side of the transformer, we may take a large current at low voltage from the other side. There is no gain in energy; there is a loss, for the resistance of the wire to the flow of current has to be overcome.

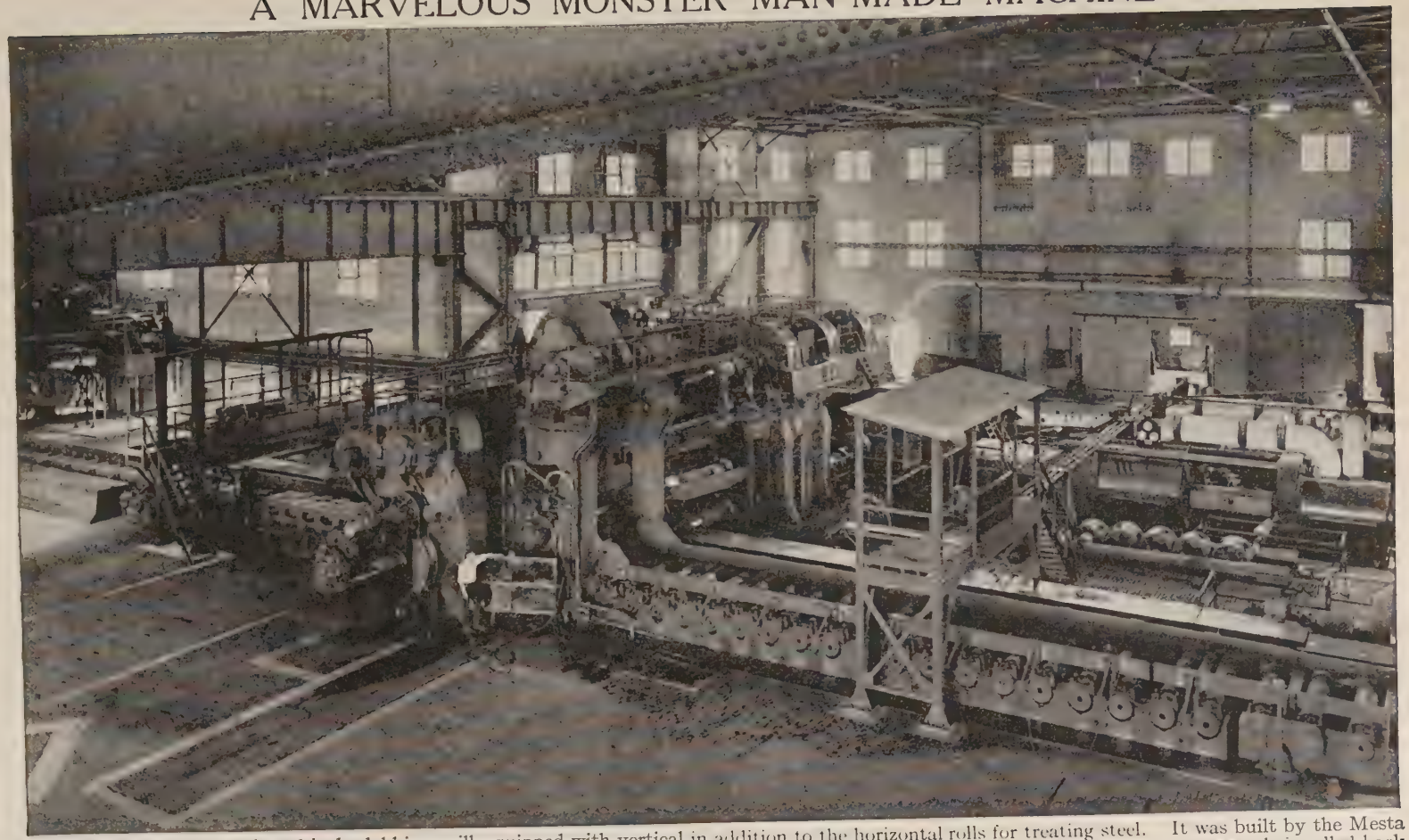
As has been mentioned, the operation of machines is always attended by a loss of energy in overcoming friction. To a large extent this loss can be eliminated by the use of proper lubricants. In the present age of high speeds and high temperatures, mineral oils are the only lubricants which will stand the strain imposed on them. In using them man is drawing on a natural source of energy.

Let us take stock of our sources of energy and then discuss them separately. For industrial purposes energy is derived from:

(1) The muscular power of men and animals
(2) The radiant energy from the sun
(3) The energy of the winds
(4) The internal heat energy of the earth
(5) The energy of fuels
(6) Chemical energy
(7) Gravity and gravitation

Strictly speaking, all but the last of the above sources of energy may be referred back primarily to the sun.

A MARVELOUS MONSTER MAN-MADE MACHINE



This illustration shows the 46-inch slabbing mill equipped with vertical in addition to the horizontal rolls for treating steel. It was built by the Mesta Machine Company of Pittsburgh. The horizontal rolls are 36 inches in diameter and 84 inches in length. An ingot weighing 50,000 pounds is rolled back and forth through them until it has a section area of 20×60 inches. The vertical rolls keep the edges square with the top and bottom surfaces. The total weight of this mill, including engines, is approximately ten million pounds. The figure of the man in the foreground will give an idea of its size.

The muscular power of men and animals

In ancient and in slavery times the work of man as a machine was of considerable importance. Undoubtedly the Pyramids and great temples of the Egyptians were built with manual labor aided by the lever and the inclined plane.

The comparison of work done by various machines is based on that done by the horse, determined by experiments made years ago by James Watt. The supposed ability of a horse to do 33,000 foot-pounds of work per minute is a rating far too high for his continuous effort and can be sustained for only short periods. A much fairer figure, as far as the horse is concerned, would be 25,000 foot-pounds, but in the comparison of engines with each other, 33,000 does as well as any other arbitrary rate. When we consider that some of our large engines can do work equivalent to that of 5000 horses, it makes little difference whether 3000 or 7000 horses would be required to do the same work. The horse-power of some of our battleship steam turbine plants is rated at over 50,000. Any of these numbers of actual animals would be equally impossible to apply to the work, but the fact that it is called "horse-power" is interesting.

Radiant energy from the sun

Experiments made by various observers on the work done by man in pushing, pulling, carrying and lifting weights seem to indicate that one-tenth of a horse-power is about the limit in rate for a man working eight hours per day. For short periods $\frac{1}{3}$ horse-power has developed, but for continuous work throughout the day a man is probably most efficient when working one-third of his day of 24 hours at a speed and exerting a force one-third of his maximum.

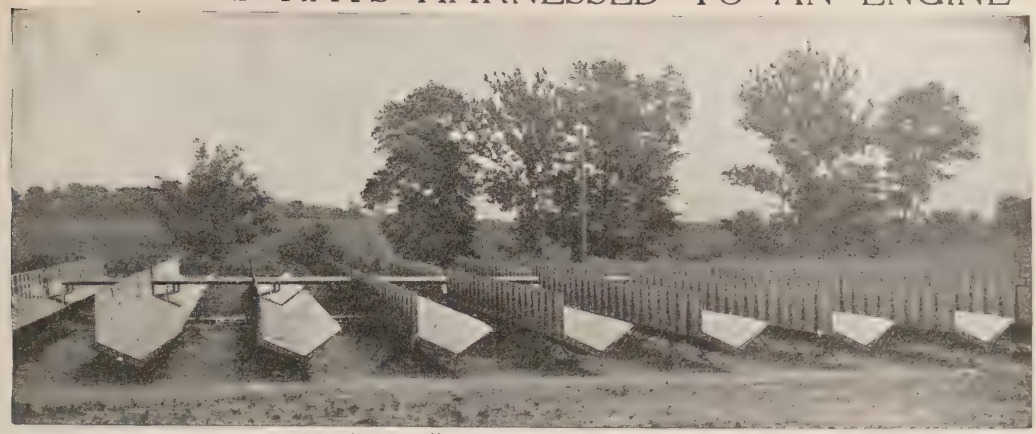
There are, of course, conditions of labor under which man and the horse cannot be displaced by machines, but these are becoming fewer every day.

As light and heat, the radiant energy of the sun is responsible for the vegetation of the earth which makes animal life possible, and this vegetation in millions of years gone by has formed our coal and peat. The snow and rainfall are due to the sun, which has lifted from the oceans and lakes water which later falls back to earth and gives us our brooks and rivers. The water of these streams in its fall toward the sea is a source of energy. The winds are due to solar energy, for air rising from a heated region produces a lowering of atmospheric pressure toward which air flows from colder parts of the earth. Taken directly in the form of heat, solar energy is now and undoubtedly will be more used for the production of power. The Eastern-Sun-Power Company is operating in Cairo, Egypt, an engine driven by low-pressure steam generated in a boiler heated by the sun's rays. Reflectors are so placed that the sun's rays are concentrated, and directed against a zinc boiler covered with a heat absorbing paint. Either the boiler or the reflector is moved to compare with the sun's motion, and thus keep the rays always on the boiler. In Texas there is a similar solar plant, the engine driving a pump which supplies water for irrigating purposes. Such plants depend for continuous action on constant sunlight, and hence can be used only during daylight hours. Cloudy weather is to a solar plant what no wind is to a windmill. There are, however, in America and in northern Africa vast tracts of waste land on which the sun shines every day for months at a time. These districts may in time become centers of power for hundreds of square miles of the surrounding country. It has been estimated that in Egypt over 200,000,000 H.P. in solar energy is delivered by the sun per square mile. If even 80 per cent of this energy could be utilized by a sun-power plant it would be sufficient for the needs of the whole of Europe.

The energy of the winds

Primitive man by stretching a sail of skin used the energy of moving air to propel his rude craft, and today ships with four, five and even seven masts are sailing the oceans. If engines were used to drive them we should find from 1500 to 5000 horse-power necessary.

THE SUN'S RAYS HARNESSED TO AN ENGINE



THE LONG ROWS OF WATER-"BOXES" WHICH CATCH THE SUN'S RAYS TO GENERATE STEAM

THE HUGE PIPES INTO WHICH THE STEAM PASSES FROM THE WATER-BOXES SHOWN ABOVE

THE ENGINE DRIVEN BY THE STEAM GATHERED INTO THE GREAT PIPE FROM THE WATER-BOXES

In the twelfth century windmills came into use. Holland is still dotted with them, and in an improved form the windmill may yet become an important device for obtaining mechanical power. Like the solar engine the windmill is intermittent in action, for the winds are contrary and may or may not blow. Until some way is devised for storing up energy to be used in calm periods, the windmill cannot become a dependable source of power. Reports of the U. S. Weather Bureau show that rarely over 3000 out of a possible 8800 hours in the year is there a favorable wind of 10 to 20 miles per hour for their use. Higher is likely to injure the mill.

The internal heat energy of the earth

Scientists have often been attracted by the possibilities of utilizing the heat of the earth's interior for power purposes on the surface. Not many years ago the famous French astronomer Camille Flammarion proposed to sink a huge shaft into the earth and use the heat thus obtained for driving engines. In the digging of such a shaft there would probably be no insurmountable difficulties, but for 100 H.P. it would be necessary to sink such a shaft three miles below the surface and make it almost 600 feet in diameter. Such an undertaking would be unbusiness-like, to say the least.

The nearest approach to such a shaft is the utilization of steam generated by volcanic heat. In 1917 Professor Luiggi of the University of Rome reported that three 4000-H.P. plants were operating in Tuscany, using the heat from steam formed underground. From numerous fissures in the side of a mountain from which the steam issued, iron pipes 15 to 20 inches in diameter were driven down 300 to 500 feet into the ground. This steam direct from the point of generation, and under pressures of from 30 to 75 pounds and at a temperature from 300 to 3750 F., was used for driving a low-pressure turbine of special design. Frequent repairs, due to the action of borax salts and hydrogen sulphide gas, have led to a change in the method of using the steam. Previously it went from the ground directly in the turbine, but now it serves as the heating agent in a specially designed boiler, following which

Photo Ewing Galloway, N. Y.

COMMERCIALIZING VOLCANIC HEAT

Remarkable close-up view of the white-hot fire hole in the volcano of Kilauea on the island of Hawaii. The Volcano Research Association is to drill deep into the hardened lava about the vent to determine whether the heat is sufficiently regular to be used for generating power.

Photo Haynes, St. Paul

OLD FAITHFUL GEYSER, YELLOWSTONE NATIONAL PARK

© Underwood & Underwood, N. Y.

The roar of steam issuing from the Black Growler startles tourists in the Yellowstone National Park, and its intense heat kills the trees and makes approach, even from windward, uncomfortable — as you see.

GENERATED IN EARTH'S BOILER ROOM

Photo Publisher's Photo Service

Giant Geyser, Yellowstone National Park, in winter. The condensing steam turns to snow and ice.

© E. M. Newman

Vast volumes of steam escaping from thousands of crevices near the crater of Halemaumau, Honolulu.

it passes through an economizer for heating the feed-water. Fresh water can thus be used for making steam for the turbine, and pressures of about 30 pounds are available. The turbines are connected to electric generators which give 6500 volts. Oil transformers advance the voltage to 36,000 and the high voltage transmission lines carry the electricity to the surrounding small towns for power and lighting. During the war, the power was used by day for munition factories and at night a small part was available for lighting purposes in the town. An additional 100,000 H.P. is still possible in such districts by continuing the development of power in the manner described. In the United States there are to be found in Yellowstone Park numerous opportunities for just such exploitation of the earth's interior heat, and without question sufficient power for the whole Pacific Coast could be developed.

Chemical energy

In the chemical combinations of the materials of our earth we have such a vast tract of unexplored knowledge that it is not unlikely that chemists and physicists will, by their achievements, place new and tremendous sources of power within the reach of the engineer. If the cost of suitable material was not prohibitive, the energy of chemical combinations could be used for obtaining electricity directly. In the electric battery we have an example of chemical change producing a motive force. Since Alexander Volta showed that electricity could be generated simply by heating two different metals in contact with each other, new ideas for the production of power have excited the imagination of scientific men. The electrochemical methods of exploiting some of the main sources of power present many and great advantages over the heat methods that are still in general use.

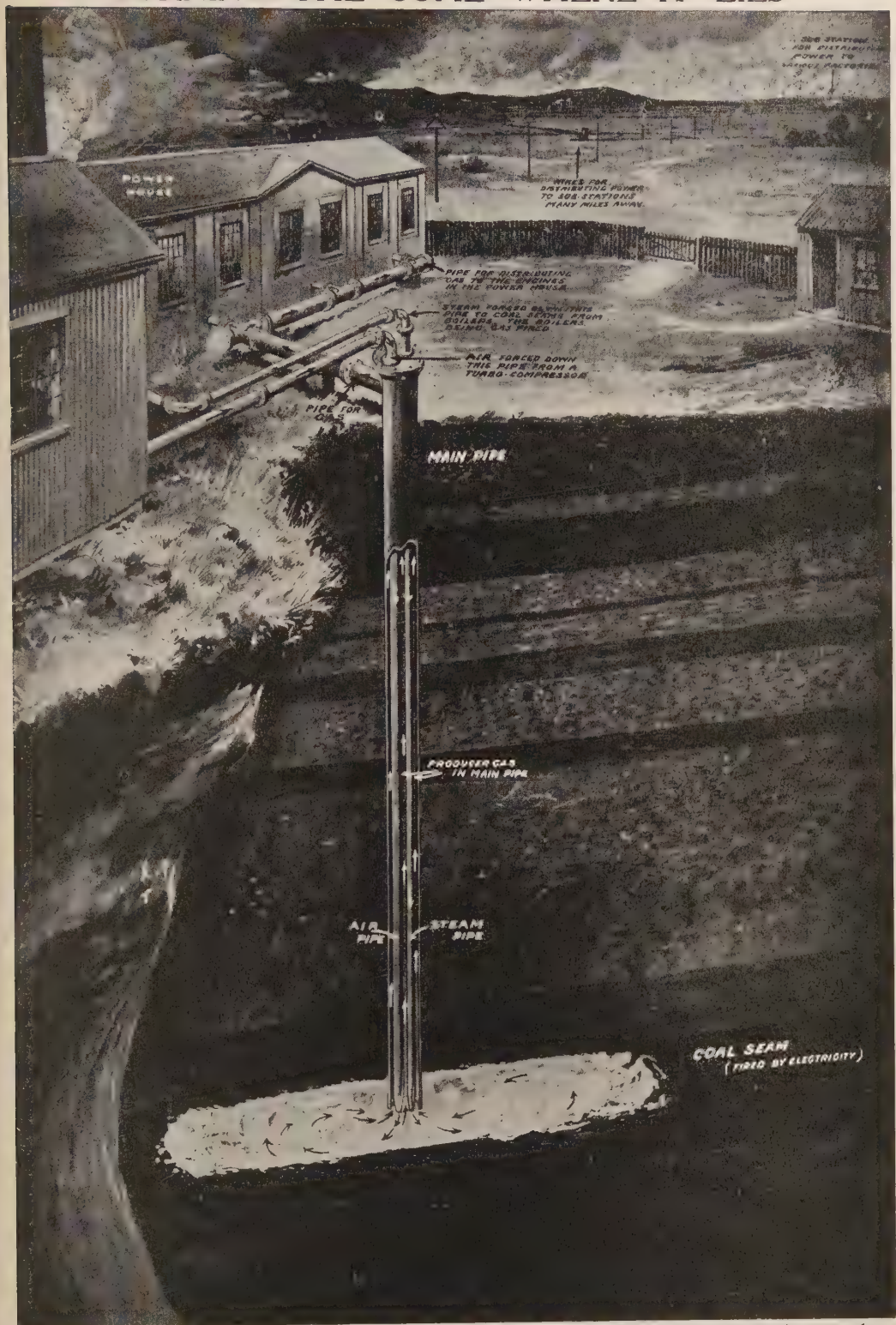
In heat methods we change chemical energy into heat, then heat energy into mechanical energy, and most of our electricity is obtained by further transforming mechanical energy into electrical energy. In many city homes we have gone backward from this point and have changed electrical energy back into heat energy, a most costly method of getting heat when it could have been obtained directly from the same kind of fuel used by the electric lighting and power company under its boilers. However, the convenience and cleanliness of heat obtained through electricity is sometimes the determining factor in its use.

Were it possible to use the carbon of coke directly as the positive element of an electric battery, a much greater proportion of the natural energy of coal could be turned directly into work than now is; but, unfortunately, though slight success has been attained in such use, carbon is very nearly at the bottom of the list of possible elements for a battery, and being electronegative to all but a few others, the choice of a suitable negative element is limited. The construction of batteries using coke as the positive element is costly and cumbrous, and though methods have been devised by Reed and Jaques for such use, the voltage is low and it is unlikely that the power problem will be solved along this line.

There are among the chemical elements certain ones, notably platinum, which hasten the chemical combination of two substances. For instance, a pinch of powdered platinum will suddenly turn sulphur dioxide into sulphuric acid without any loss or change whatever in the platinum. Numerous other instances might be given, but the most common is found in the little pocket cigar lighter in which a very fine platinum wire, when held over the vapor of alcohol, becomes red-hot and ignites the vapor. This action is called "catalysis" and the platinum is the catalyzer. Possibly a catalyzer may be found which by its action will quickly release the energy of substances which now requires years.

The chemist may, as he has already done in the case of indigo, camphor, etc., find a process for making gasoline and oils instead of pumping them out of the ground. The field of synthetic chemistry has hardly been entered, and nothing that the chemist may discover will much surprise us, to such wonderful things in the recent past has he accustomed us.

BURNING THE COAL WHERE IT LIES


POWER HOUSE
WIRES FOR DISTRIBUTING POWER TO SUB-STATIONS MANY MILES AWAY.
PIPE FOR DISTRIBUTING GAS TO THE ENGINES IN THE POWER HOUSE.
STEAM TURNED ON WITH PIPE TO COAL SEAM FROM BOILERS, THE BOILERS BEING GAS FIRED.
AIR FORCED DOWN THIS PIPE FROM A TURBO-COMPRESSOR.
PIPE FOR GAS
MAIN PIPE
PRODUCER GAS IN MAIN PIPE
AIR PIPE
STEAM PIPE
COAL SEAM
(FIRED BY ELECTRICITY)

It has been suggested that the firing of coal seams *in situ* might provide cheaper gas and power than if the coal were burned at the surface. The above diagram illustrates the suggestion.

1983

The energy of fuels

Before taking up fuel energy it should be noted that in burning coal, wood, oil or any other substance, a chemical process is undergone, for burning is simply a rapid combining of the substance with oxygen. The chemical combination of carbon with oxygen in the furnace under a boiler produces the heat necessary for turning water into steam.

Wood, the first of man's fuel stores, once so abundant in the world's vast forests, has been recklessly, even criminally, wasted. Until it was realized that coal was a more suitable fuel for industrial power purposes, wood was burned under steam boilers. In certain localities it is still used, not in preference to coal but because it is near at hand and costs to cut and haul less than the transportation alone of coal. But the greatest destruction of our forests by the hand of man has been due to the enormous use of wood pulp for paper-making. So flagrant was the abuse in denuding wooded tracts, so profligate the exploitation of timber land, that the government has had to limit the amount of lumber which may be cut. By careful thinning out of the trees, it is possible to keep the remaining timber growing, but when completely stripped, as thousands of acres have been, there is no hope of future growth, for with nothing to retain the rain the water runs off the hills and mountain sides as fast as it falls, giving no sustenance for vegetation. Dry brooks become raging torrents for a brief period and then subside until the next storm. This fact will again be mentioned when we come to consider water-power.

Coal, from which most of our commercial power is derived, is being rapidly exhausted and we may expect from now on to be forced to use poorer and poorer quality. There are undoubtedly many undiscovered coal fields in the world but they may be so inaccessible or so far from the point of ultimate use that the cost of transportation will be prohibitive. To eliminate the labor and cost of mining and transportation it has been suggested that the coal be burned as it lies in the earth and the gas thus produced brought to the surface through pipes and used to drive gas engines, which are so much more efficient than steam engines. This plan may be tried some day and, if practicable, would without question put off for centuries the time when coal will be exhausted. But it presents difficulties and dangers, for the proper mixture of air with the gas thus generated would result in explosions with disastrous results to the power plant. It is possible, however, that the coal might be burned at the surface near the mine, and used to generate electricity, which on high voltage transmission lines could be sent hundreds of miles into the surrounding country. This would eliminate the cost of transportation and save also in the consumption of the fuel, for one large plant can be much more economically operated than a dozen small ones.

The United States, Mexico and Russia have enormous oil fields. Oil, because of its ease in handling, its cleanliness, its convenience in storage, and its higher heating value for the same weight, is coming into extensive use, not alone for our ships on the sea, but also for stationary power plants.

The lightest distillates are used for the internal combustion engine, which is demanding an ever increasing supply, so great, in fact, that the gasoline of today is nearly as low in volatility as the kerosene of ten years ago. With improved devices for mixing air with it and vaporizing the liquid fuel, we may expect this lowering of the volatility to continue. The introduction of "fuelizers", "hot spots", and other preheating appliances have already accomplished wonders. The Diesel engine proper, which operates with the heaviest of the mineral oils, and its near relative, the Semi-Diesel, which burns kerosene and even heavier distillates, are demanding only a fraction of their ultimate needs. Mineral greases and oils for lubrication, road construction, etc., are also drawing on the available supply. Fortunes are made overnight when oil is discovered, but though new wells are driven every hour in the day the demand still exceeds the supply.

THE THUNDERING CATARACT'S FORCE

© Publishers Photo Service

NATURE'S GIFT TO MAN — WATER POWER

Gravity and gravitation

Gravity is the pull of the earth on bodies, while gravitation is the pull of one body on another. For example, if two apples on strings are suspended from a beam, the pull of the earth on the apples is due to gravity; the pull of one apple on the other is due to gravitation. In small masses the attraction of gravitation is small, nevertheless it can be shown by the physicist by extremely delicate instruments. When we consider masses such as the earth, the moon, the sun and the other members of the solar system, it can be seen that enormous forces are at work. The action of the tides is due to the pull on our earth exerted by the moon. Probably the ground itself is somewhat distorted by this pull, but not being fluid, as is the ocean, we do not notice it.

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THE ENERGY OF THE WAVES

Surf beating on the rocks at Mollendo, Peru.

Tidal energy has long been utilized and the most successful tide machines have been those taking advantage of the rising tide for storing water in tanks or basins, from which it is passed through old-fashioned, undershot water wheels or turbines. At Rockland, Maine, however, is a 5000-H.P. plant using the tidal water for compressing air, which is then employed instead of steam for driving an engine. There are two shafts sunk in the earth to about 200 feet, connected at the bottom by a horizontal tunnel. The water falls through one shaft and rises through the other. Air, carried down with the falling water, is compressed to almost 85 pounds. At the bottom of the shaft the air is separated from the water and rises through a 14-inch pipe to the engine.

The water turbine has increased the power obtainable from tidal basins. It would be out of the question to construct by excavation tidal ponds for large power plants, but there are many natural basins which would need only to be closed in by a sea-wall in order to be converted into power reservoirs. French engineers have estimated that the tides at Honfleur, at the mouth of the Seine, might be utilized to yield power at a cost of about $60 per horse-power per year. This compares favorably with the power cost of a steam plant using coal. Experiments have been made on the Schleswig-Holstein and on the north German coasts with tidal power, and there are numerous small plants on the shores of Connecticut and New York. There are few places which have a tidal rise of over six feet. With this rise a pond six feet deep will develop about 4 H.P. per acre.

There is another way of harnessing the rise and fall of the tides by using floats and transmitting the power ashore. The weak point of this method is easily seen by figuring the energy of a falling weight. For the development of 100 H.P. with a 6-foot tide it would be necessary to have a float weighing 100,000 tons. The *Aquitania* and *Leviathan* if combined into one float would produce only about 78 H.P.!

Allied in principle to the tide motors are devices operated by the rise and fall of floats or buoys due to wave motion. It is doubtful if either of these latter types of power plants will ever come into general use. On a large scale they would generally require capital investment incommensurate with the power return. There are, however, certain spots, notably the Bay of Fundy on the east coast of Canada, where the natural configuration lends itself to such a project. The tidal rise here is almost 40 feet, and daily millions of possible horse-power hours run to waste. By building a sea-wall three miles in length across the narrow gap of two of its headlands, this power might be utilized. Such an engineering project would try man to his utmost and tax the resources of a nation, but the return would be a yield of power a hundred times greater than that of Niagara.

It will be seen from what has been said that gravity is really the ultimate force used in tidal machines. To be sure, it is the force of gravitation which causes the rise of the tide to fill the tidal ponds, but gravity is the force which later causes the water thus stored to fall again through a water-wheel. Our greatest use of gravity alone as a force in the development of power is in the utilization of the energy of falling water. With dams we are able to regulate the flow of brooks and rivers, make storage basins, and provide a water level from which the fall of water to a turbine wheel may be used to generate electricity.

LONG LAKE STATION OF THE WASHINGTON WATER POWER CO. OF SPOKANE
70,000 horse-power is developed.

The hydro-electric stations already in operation, most notably the monster plants at Niagara, have barely touched the untold power which is now flowing daily to waste in our rivers and falls. Regulation of flow in rivers will secure a continuous average yield of power which can be maintained over long periods, even with diminished rainfall. At present some water-powers are useless at certain seasons due to low water. By damming and reduction of flow, these can be made to operate continuously. If water-power is developed in the United States there will be no trouble whatever in getting 300,000,000 H.P. with no use of fuel whatever!

Norway owns 31 waterfalls, or systems of falls, and controls 141 others. These falls are capable of developing 150,000 H.P. without regulation. Under proper control 750,000 H.P. can be obtained.

It has been proposed that national forest lands in the United States be leased for a term of years for the production of water supply by private corporations, subject to government regulation. Many people favor government ownership of natural resources. At present private interests are impeding, and probably will continue to obstruct government control, but undoubtedly the final outcome will be such control, and possibly operation.

One of the greatest water-powers of the world, Niagara, is limited in its possibilities by sentiment. To be sure, these falls are sublime in their grandeur, and it would seem a shame to destroy their beauty by drawing off the river by flumes to the extent of cutting off all flow over the falls. However, this is unnecessary; by increasing the amount of water used by the power plants at night only, cities for hundreds of miles around could be supplied with electricity for lighting. The millions thus benefited would offset the hundreds who could no longer view the falls by moonlight.

Many potential water-power sites have been either destroyed or crippled by the ruthless cutting of timber on the watersheds adjacent to the fall. They assume the aspect of miniature Niagaras during a heavy rainfall, only to present a mass of dry rocks on the following day. Such practices must be stopped, and the government must protect the watersheds if the millions of possible water horse-power are to be saved for either our own use or for that of the coming generations.

The strongest recommendation of water-power is in its replacement. Coal and oil once burned are gone forever. Man cannot replace them, and nature's creation is a process of millions of years. Water, after doing its work, reappears again on reaching the sea by way of the clouds and rainfall.

Photo National City Bank, N. Y.

IMATRA RAPIDS IN WINTER

An example of Finland's water-power resources.

Possibilities of other fuels

Before bringing our discussion of power sources to an end, let us consider for a moment two promising sources of fuel: vegetation, and the oil-bearing rocks of Scotland, Canada, the United States, Australia and Serbia.

Alcohol, made from potatoes, beets, sawdust and cereals may have to be used for internal combustion engines instead of the petroleum distillates. It has been claimed that it can be produced at a cost of 5 to 10 cents per gallon. In Germany before the Great War it was sold as low as 15 cents per gallon. Alcohol, for use in internal combustion engines, has some disadvantages; if pure, the engine must be started with gasoline. Addition of 10 parts of gasoline, however, is sufficient in warm weather. The compression pressure for alcohol is increased to 180 pounds per square inch, as against 50 to 90 for gasoline. This means that the cylinder walls must be very much stronger and probably heavier, for the maximum pressure is over 500 pounds per square inch as against 300 pounds for gasoline.

As advantages on the side of alcohol, there are the smaller carbon deposits in the cylinder and elimination of obnoxious odors in the exhaust. For engines of the same size nearly 30 per cent more power for alcohol using 180 pounds compression pressure can be obtained at the same volume rate of fuel use. For the same power, this would mean greater fuel carrying capacity for automobiles.

In considering the depletion of oil-well supplies, we must remember that in oil-bearing shales we have a source of petroleum which will furnish millions upon millions of barrels. These oil shales are found in several parts of the world, notably in Scotland, which supplies part of the demand of the British navy, and in the western part of the United States in Utah and Colorado.

The process used for obtaining oil from the rock is that of distillation. A small amount may actually be squeezed out of the rock by pressure, but large amounts, from 40 to 90 gallons per ton of rock, are obtained by heating the rock and distilling the vapors driven off. Besides oil the process yields as a by-product ammonium sulphate used for fertilizer. Scottish shales produce about 18 per cent of oil and 2 per cent of fertilizer, while the American shales yield 40 per cent oil and 6 per cent of fertilizer. Furthermore, the American shales are more accessible by far than the Scottish, which are below the surface and require mining. In America much of the oil-shale is found above a valley bed and could be handled by steam shovels.

There are in North Dakota and Montana vast beds of lignite, sometimes called "brown coal." Lignite is coal in the making, and if subjected to pressure and heat for millions of years it would eventually become bituminous coal. Its heat value is about half that of the black coals in use today, but it does not hold together and cannot be burned under a boiler with the ease and advantage of the denser fuels. However, tests have shown that for gas-producer use it serves the purpose admirably. We may expect, then, that engines driven by gas from lignite fuel gas-producers will utilize this source of fuel, which is abundant. Even excluding Alaska from our calculations, there are 740,000,000,000 tons available in the United States, one-third of which is on public lands.

Undoubtedly there are in the universe unknown forces as yet untouched by man, which may some day be brought to work for him. The magnetic forces of the earth may be one of these, but his greatest present-day hope is in the conservation of our natural fuels by eliminating wastes and by improved utilization. Alcohol will undoubtedly displace, or rather replace, the use of petroleum distillates in the internal combustion engine, barring the synthetic production of a fuel having the characteristics of gasoline and kerosene, or the discovery of a new fuel for such use. Our water powers must be conserved and protected, by rigorous government control if necessary, for unless a new source of fuelless energy is discovered, water must become by development the main reservoir of energy for the power generation of the future.

AMERICA'S MERCHANT MARINE

The Shipping Revolution Which Was Brought about by the Great War

NEW NATIONAL PROBLEMS CONFRONTING US

CHAPTER 14 told the story of the decline of American shipping. We have now to deal with its swift and dramatic recovery, and with the new problems which that recovery has created. In 1910, just before the Great War, the United States had only one ton of shipping for every twenty possessed by Great Britain; in 1920, the American fleet was two-thirds as large as the British, and the second largest in the world.

At the outbreak of the war, the total steam sea-going merchant tonnage of the world amounted to approximately 41,500,000 gross tons. The Allies and the neutral nations lost altogether over 15,000,000 tons during the war, largely through the agency of submarine operations and mines. Over one-third of the world's tonnage was destroyed. Nevertheless, in the tremendous struggle for the winning of the war the building of ships was prosecuted at such an enormous rate that by 1920 the losses had been fully restored, and, the world's tonnage is now much larger than it has ever been.

This does not mean that the pre-war shipping situation has been restored. Losses and new construction have not been evenly distributed among the different nations. Many of Germany's ocean-going ships were seized by her enemies during the war, and most of the rest were turned over in accordance with the provisions of the treaty of peace. Great Britain lost 9,000,000 gross tons — nearly half her total shipping — but by 1921 she had been able by means of war seizures and new construction to bring her tonnage up to its pre-war amount.

Other countries, including France, Italy, Japan, Holland, Norway and Spain, also made substantial net gains during the same period. But by far the most spectacular and significant advance was made by the United States, whose sea-going vessels amounted to only 2,000,000 gross tons in 1914, and to over 13,500,000 in 1924.

THE WORLD'S SHIPPING BEFORE AND AFTER THE GREAT WAR

Country	1914	1924
	Gross Tons	*Gross Tons*
United Kingdom	18,892,089	19,105,838
British Dominions	1,631,617	2,772,660
United States:		
Sea-going	2,026,908	13,530,544
Great Lakes	2,260,441	2,361,464
Austria-Hungary	1,052,346	
Belgium	341,025	560,597
Brazil	307,607	464,734
Denmark	770,430	1,035,943
France	1,922,286	3,498,233
Germany	5,134,720	2,953,671
Greece	820,861	761,210
Italy	1,430,475	2,832,212
Japan	1,708,386	3,842,707
Netherlands	1,471,710	2,556,417
Norway	1,957,353	2,505,393
Spain	883,926	1,239,521
Sweden	1,015,364	1,254,550
Other countries	1,778,000	238,446
Total steam tonnage	45,403,877	61,514,140
Sail tonnage	[1] 3,685,675	2,509,427
Grand total	49,089,552	64,023,567

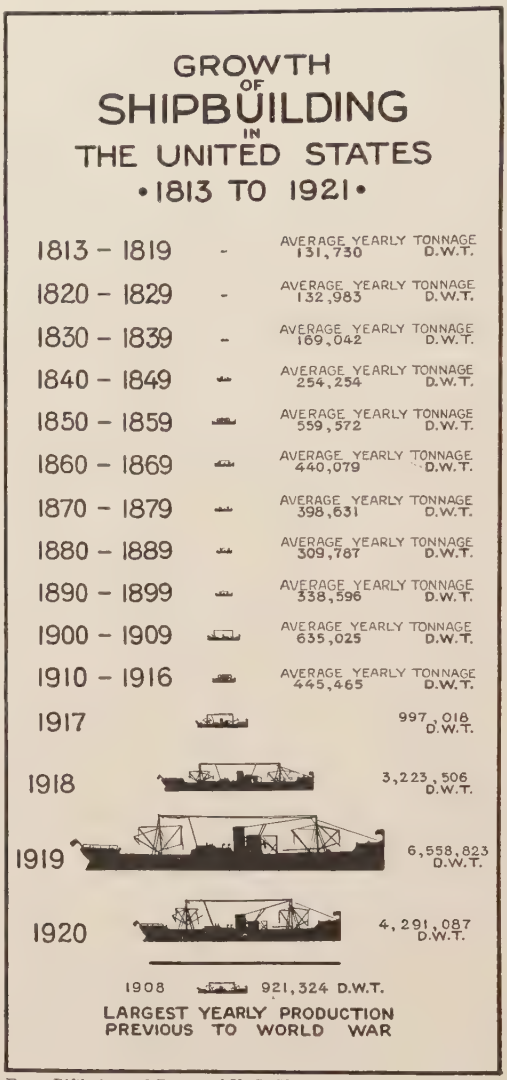
[1] Net tonnage

A small and relatively unimportant factor in this increase was the change in laws of the United States so that vessels built in other countries might, if American-owned, be registered as American ships.

About half a million gross tons of shipping were thus brought under the United States flag, but a large part of the vessels thus transferred were already owned by Americans, even though, for various reasons, they had been sailing under foreign flags.

In 1916, before the United States entered the war, it established a Shipping Board to forward American maritime interests and to acquire by building, or in other ways, the merchant vessels that our trade needed. Upon our entering the war, the Shipping Board promptly organized the Emergency Fleet Corporation to take charge of the government's ship-building program.

All of the larger American privately-owned steam vessels were requisitioned for government service. Tonnage was even transferred from the Great Lakes—vessels which were too large to go through the intervening locks being cut into sections and floated through on their sides. Some ships were chartered from foreign countries. German ships interned in American ports were seized. But the most important additions to the American fleet came from the construction of new vessels in American yards. The Emergency Fleet Corporation entered upon the tremendous task of building about 12,000,000 gross tons of shipping. About 1,800,000 tons of the proposed number had been completed when the armistice was signed. Immediately the problem of ship-building became that of preparing for peaceful commerce rather than for war. The further building of wooden ships, which had not proved themselves successful, was stopped and many contracts for the building of steel vessels were canceled.


GROWTH OF SHIPBUILDING IN THE UNITED STATES
•1813 TO 1921•
1813 - 1819 - AVERAGE YEARLY TONNAGE 131,730 D.W.T.
1820 - 1829 - AVERAGE YEARLY TONNAGE 132,983 D.W.T.
1830 - 1839 - AVERAGE YEARLY TONNAGE 169,042 D.W.T.
1840 - 1849 - AVERAGE YEARLY TONNAGE 254,254 D.W.T.
1850 - 1859 - AVERAGE YEARLY TONNAGE 559,572 D.W.T.
1860 - 1869 - AVERAGE YEARLY TONNAGE 440,079 D.W.T.
1870 - 1879 - AVERAGE YEARLY TONNAGE 398,631 D.W.T.
1880 - 1889 - AVERAGE YEARLY TONNAGE 309,787 D.W.T.
1890 - 1899 - AVERAGE YEARLY TONNAGE 338,596 D.W.T.
1900 - 1909 - AVERAGE YEARLY TONNAGE 635,025 D.W.T.
1910 - 1916 - AVERAGE YEARLY TONNAGE 445,465 D.W.T.
1917 - 997,018 D.W.T.
1918 - 3,223,506 D.W.T.
1919 - 6,558,823 D.W.T.
1920 - 4,291,087 D.W.T.
1908 - 921,324 D.W.T.
LARGEST YEARLY PRODUCTION PREVIOUS TO WORLD WAR

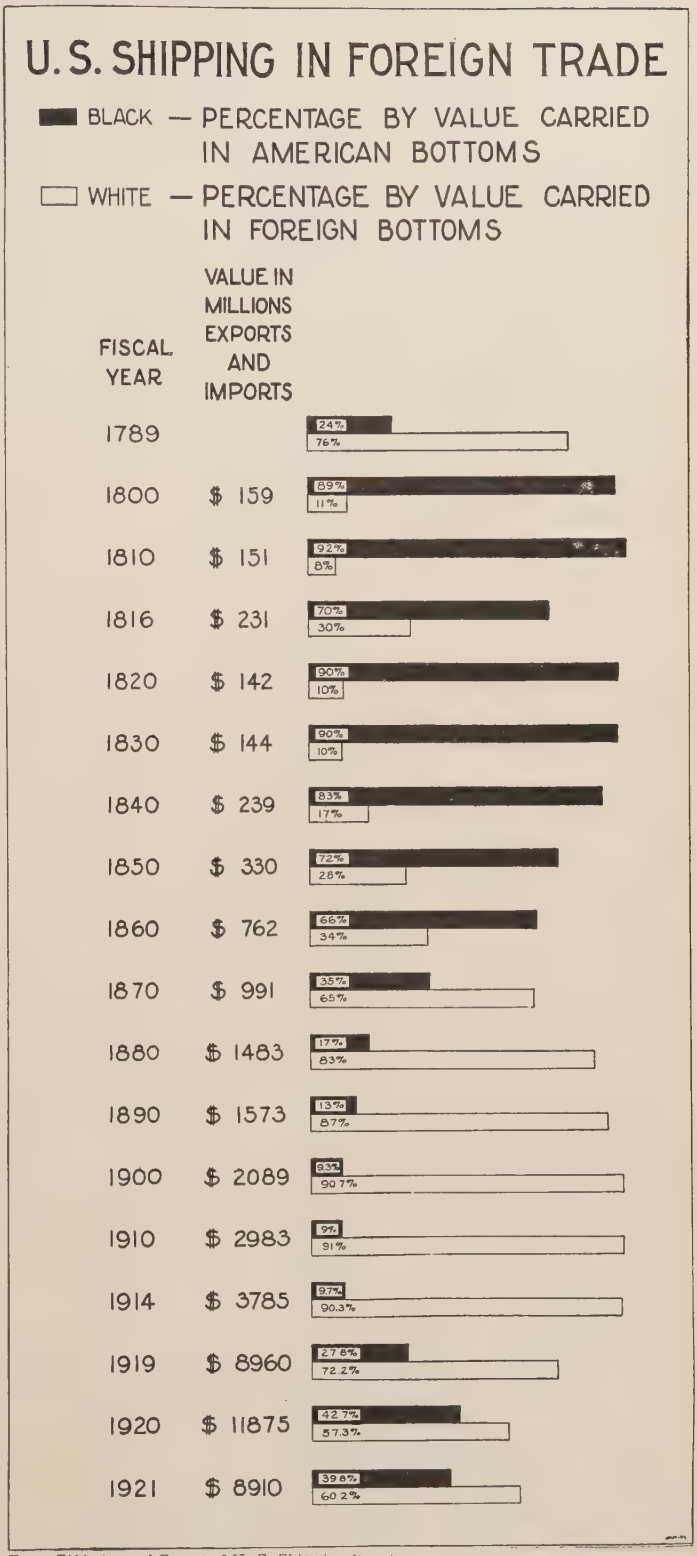
From *Fifth Annual Report of U. S. Shipping Board*

Nevertheless, the major part of the nation's ship-building program was carried out, so that by the end of 1920 more than 2350 vessels, aggregating 9,000,000 gross tons, had been added to the American merchant marine. The foreign and the privately-owned vessels that had been requisitioned by the Shipping Board were gradually released, but the vessels owned and built by the government remained under its control. Public opinion, supported by the judgment of experts, was against the continued governmental operation of ships. It was therefore decided to sell the government vessels to private owners. Unfortunately, there were two obstacles in the way.

In the first place, the government ships had been built under conditions which made them extremely expensive. New plants had to be constructed at top speed regardless of cost. The number of steel ways in American shipyards had been increased from less than 150 to nearly 400; ways in wooden yards, from 73 to about 420. Some of the new yards were the largest in the world, equipped to turn ships out rapidly and in the long run at relatively low costs.

But with the shipbuilding program suddenly terminated, overhead costs, including the costs of constructing the yards themselves, were exceedingly high in proportion to the number of ships built. Moreover, the ships were built when materials, wages and other expenses of production were high, and when for these reasons, as well as on account of its scarcity, shipping commanded the highest price per ton ever recorded. In short, for reasons that were in large measure inevitable, the government ships were built at extremely high cost.

In the second place, beginning with 1920, a period of severe industrial and commercial depression was encountered. With relatively little demand for ocean transportation, shipping rates were low, the shipping business unprofitable, and the market for ships consequently poor. By June 30, 1921, 380 ships, aggregating 1,200,000 tons, had been sold for barely $300,000,000—a sum very much less than they had cost the government. Other ships which had been sold by the government were returned by purchasers who were unable to complete their payments. Even if general commercial conditions had been favorable, it would undoubtedly have been found that the United States had more ships than it could profitably use in the pursuit of its various commercial activities.



From *Fifth Annual Report of U. S. Shipping Board*

To carry the American foreign trade alone might require in normal years as much as 12,000,000 tons of shipping. But no country carries all of its own trade; even Great Britain before the war carried only about two-thirds of its commerce. It is therefore clear that not over 8,000,000, or at the most 10,000,000, tons of American shipping are likely to be required in the service of American trade for some time to come.

The sale of some surplus American tonnage to foreign interests was therefore deemed necessary. Unfortunately, the world as a whole found itself by 1920 with more ships than it needed. So unprecedented had been the rate of construction that it is estimated that the world had fully as many ships as if there had been no war, while on the other hand, by reason of the war, the world's commerce had decreased. These conditions are not likely long to endure. Ocean shipping has from the beginning been subject to extraordinary ups and downs. With the recovery of the world's trade there will again be a ship shortage and this will result in a renewed impetus among American builders to the construction of additional ships.

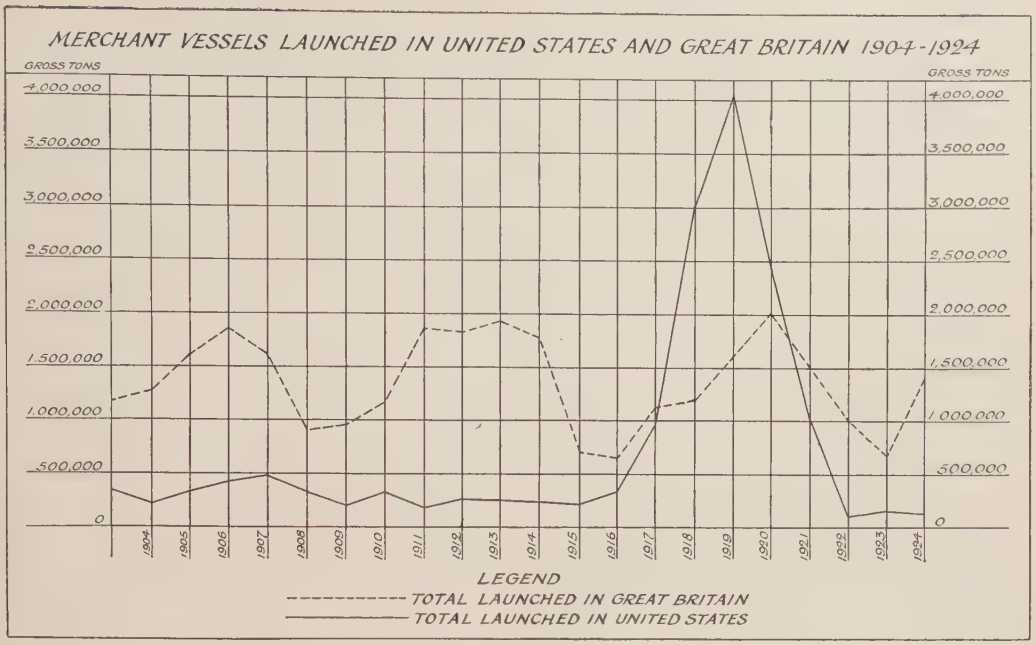
The Shipping Board compelled to carry on in the operation of government vessels

However desirable the sale of American ships to private interests, including foreign interests, might have been, it was under all of the conditions a program impossible of prompt realization. Therefore the United States Shipping Board was virtually compelled by circumstances to continue the operation of government vessels. In 1921, it owned and controlled 1740 ships of nearly 8,000,000 tons, but of this number 900 boats, representing as much as 3,500,000 tons, were tied up and actually inoperative.

Four years after the end of the war, therefore, the great merchant marine which, under the pressure of war needs, had been conjured into existence as though by Aladdin's lamp, seemed to be melting away. Some ships were being disposed of to foreign owners, others were rusting in American shipyards.

To a people, like our own, rightly proud of its maritime traditions, this seemed a humiliating outcome. General depression of the world's shipping industry complicated the situation. It made it difficult to determine how many of the obstacles in the way of profitable American operation of American ships were temporary, and how many were permanent. Prices, wages and costs of construction and operation were in a shifting and unstable condition the world over. It did not appear, however, to careful students of the problem that costs of construction were necessarily any higher in the United States than in other countries, while it was clear that they were distinctly lower than in most. Of course, ships built and bought during the war and the two years following cost an exorbitant sum. It was clear that in some way a large part of this sum would have to be written off as a war cost. American shipping interests could not be permanently burdened with the payment of interest and depreciation charges on these abnormally high capital costs. The ships, if they were to pass into private hands, would have to be sold at market prices, even though it might be necessary to wait some years until the recovery of trade and a renewed demand for shipping had brought the market prices of vessels to a higher level.

There were pessimists, however, who, granting this much, prophesied a new decline of American ocean shipping to something approximating the lowly position it occupied before the war. American costs of operation, it was charged, were higher than those of other countries, and would remain higher. Most of these pessimists had in mind the effects of the Seamen's Act of 1915, commonly known as the "La Follette Act". It provides, among other things, that at least three-fourths of the crews of ships must be able to understand orders given by the officers. This makes it impracticable for vessels to employ cheap Asiatic crews. Moreover, at least sixty-five per cent of the crew, including officers and apprentices, must be rated "able seaman", which means seamen who have had three years' service at sea.



Furthermore, the Seamen's Act makes it possible for the men to leave the ship in any port and to demand half of their accrued wages. This is the most disputed clause of the act. On the one hand, it is held that the old rules against desertion assured a vessel that it would not be left helpless, and assured the seamen that they would not be "beached because of a master's whim or parsimony". On the other hand it is claimed that this section of the act has emancipated the seamen from a condition resembling involuntary slavery, and that its operation has done much to raise the wage level of the seamen of other nations. Incidentally, the law has had one interesting effect — it makes it less desirable to keep the crew of foreign vessels under pay while in an American port. This has operated to stimulate the use of labor-saving mechanical devices to load and unload cargoes in port.

It is possible that the Seamen's Act will sometime be amended in detail: there is little chance that it will be repealed. In fact, there is small reason for repealing it. Sailors' wages and living conditions had for long years been far below the standards which ought to obtain in the economic life of the modern world. The Seamen's Act has admittedly done more than any other one factor to improve conditions not only on American ships but on those of other countries. Its first costs have undoubtedly fallen especially heavily upon American ship operators, but by a process of gradual diffusion and equalization of the new and higher standards, the comparative disadvantage of the American ship operator has been and will be reduced. It must be remembered, also, that the Seamen's Act applies to foreign ships as well as to American just so far as those foreign ships come under American jurisdiction, that is, so far as they enter American ports.

It should be a matter of no little national pride that the United States at some cost to itself took the initiative in such a greatly needed reform.

And another factor, although it has attracted a much smaller measure of public discussion, is likely to prove vastly more important than the Seamen's Act in determining the competitive strength of the American merchant marine. The type of ships built during the war was determined by the overwhelming necessity of getting a maximum number of ships in the shortest possible time. Standard sizes which, in

view of the existing ship-building equipment, could be turned out most rapidly were favored, without any special consideration of the fitness of these particular sizes and types to the needs of post-war trade. For example, nearly six hundred wooden vessels were wholly or partially completed. These were found to be unsuited, on account of high operating costs and other reasons, for transoceanic commerce. In 1921 hardly any of the wooden vessels controlled by the United States Shipping Board were in operation. Eventually, it is probable, most of these wooden vessels will pass into the possession of countries which can use them to better advantage in trade involving only short trips.

Even in respect of steel steamships the American merchant marine falls far short of the standards it would have reached if commercial conditions had governed its building. As compared with the British fleet, for example, the United States has a larger proportion of small ships and a smaller proportion of large ships. The proportion of fast vessels of fifteen knots and over in the British fleet is twice as great as in the American. This means that the effective strength of the post-war American merchant marine is distinctly less than is indicated by the figures of tonnage. If one ship is twice as fast as another, it has nearly twice as much carrying capacity, even if its tonnage is no greater. Moreover, it is in a position to render quicker and better service, and so to command higher rates and lower insurance charges.

The American merchant marine is likely to be further pruned by the sales of small ships and slow ships to countries which can use them to better advantage than can the United States. In the further building of ships, the peculiar needs of American commerce, with respect to size and shapes, will be taken into account, and gradually it is hoped that American shipping will be as fully and as admirably adapted to American needs as are American factories and American railways. These and similar problems involve the very important question of the future relation of the American government to American merchant shipping.

There are two ways by which different nations have tried to strengthen their own shipping interests: (1) by discriminating against the vessels of other nations, (2) by giving help or granting special favors to their own vessels. Discriminations take such forms as excluding foreign vessels from the coasting trade, imposing special tonnage dues or other taxes upon foreign vessels in domestic ports or subjecting goods brought by foreign vessels to higher customs duties than are imposed upon goods brought by national vessels. All of these methods of discrimination have been tried by different countries, but no country has merely by their use been able to build up for itself a large merchant marine. It is a striking fact that the nations which make the largest use of such discriminations have relatively weak merchant marines, while the nations with the largest shipping do not avail themselves of these petty methods. Great

AMERICAN MERCHANT MARINE IN 1924

By Power			By Material			By Location		
	No.	Gross Tons		No.	Gross Tons		No.	Gross Tons
Sail . . .	2,748	1,185,000	Wood . .	21,573	3,114,000	Atlantic and Gulf . .	15,856	11,358,000
Steam . .	7,736	14,870,000	Metal . .	5,002	14,627,000	Pacific . .	6,168	3,428,000
Gas . . .	11,014	445,000				Northern Lakes .	2,693	2,791,000
Canal . .	343	40,000				Western Rivers .	1,858	164,000
Barges . .	4,734	1,201,000						

Britain, whose domestic and colonial trade is open to the vessels of the world, still has the largest merchant marine; France and those other countries which discriminate against foreign ships have relatively small fleets.

The reservation of the coasting trade to national vessels stands on a somewhat different footing than do other forms of discrimination. Only a few countries, and Great Britain is one of these, open their coasting trade to foreign vessels.

Discriminating duties and subsidies to protect a merchant marine

The first general tariff act of the United States, in 1789, gave a discount of ten per cent from the general import duties in the case of goods imported in American vessels. In addition, discriminatory tonnage taxes were imposed on foreign ships entering domestic ports. In subsequent years, these regulations were modified, and on the whole their discriminatory character was increased. But in 1815, as a result of our own experience with countervailing taxes and duties imposed by England, Congress provided for the removal of discriminations against countries which did not discriminate against the vessels of the United States. Other difficulties between the United States and England with respect to the American trade with the British West Indies continued to be a source of continual friction, but in 1830 the West Indian trade was finally fully opened to American vessels.

During this early part of its national history, the United States negotiated reciprocity treaties with nearly all the maritime countries of the world, by the terms of which the vessels of the contracting powers and their cargoes were to be exempted from discriminatory duties. It is because of these treaties that clauses of the later tariff acts of the United States, which provide that the duty upon goods imported in foreign vessels shall be higher by ten per cent than the duty upon goods imported in vessels of the United States, have been of no particular significance.

No large amount of thought was given to the studies of these old discriminatory provisions until the revolution in the shipping situation led American statesmen to concern themselves with means of preserving the important maritime position the United States had gained as a result of the war. Accordingly, in the Merchant Marine Act of 1920, Congress provided that all the treaties which restricted the United States to impose discriminatory duties, or tonnage taxes, are to be terminated. The purpose, of course, was to open the way toward the protection of the American merchant marine against foreign competition.

WATER-BORNE COMMERCE OF THE UNITED STATES: 1821–1923

Year	In American Vessels	In Foreign Vessels	Total	Per Cent in American Vessels
1821	$ 113,201,462	$ 14,358,235	$ 127,559,697	88.7
1831	159,508,291	24,993,416	184,501,707	86.5
1841	208,030,515	41,767,465	249,797,980	83.3
1851	316,107,232	118,505,711	434,612,943	72.7
1861	381,516,788	203,478,278	584,995,066	65.2
1871	353,664,172	775,822,576	1,109,486,748	31.9
1881	250,586,470	1,269,002,983	1,519,589,453	16.5
1891	206,459,725	1,450,081,087	1,656,540,812	12.5
1901	177,398,615	1,974,536,796	2,151,935,411	8.2
1911	280,206,464	2,930,436,506	3,210,642,970	8.7
1923	11,699,702,541	7,472,238,300	19,171,940,841	60.0

This raised anew the whole question of the wisdom of this particular form of discrimination. There may be good reasons for giving special encouragement and protection to the American merchant fleet at a critical stage in its history, but the method of discriminatory duties and taxes is one which the experience of the world has proved to be useless and even worse than useless. It is useless because it leads inevitably to retaliatory duties imposed by other nations, so that the nation first using the weapon of discrimination gains no permanent advantage from it. It is worse than useless because it breeds international suspicion and distrust. The permanent banning of discriminations of this kind would be a long step forward on the path toward permanent peace among the nations. Only with the removal of such discriminations can we honestly speak of the "freedom of the seas".

Another method of encouraging a nation's merchant marine is to give it direct financial help in the form of bonuses or subsidies. Various countries have made use, and apparently successful use, of this method. France, for example, has since 1881 aided the construction and navigation of French ships by bounties, and she pays large sums, really subsidies, to certain shipping companies for carrying the mails. It was Germany's practice to aid its merchant marine not only by mail subsidies, but also by preferential railway rates on goods for export by German vessels to Africa, the Near East and other points. Japan, here as elsewhere imitating the policies of progressive Western nations, has since 1896 granted construction and navigation bounties, and in particular has given large subsidies to a limited number of important Japanese steamship "lines." Great Britain has not adopted the principle of subsidies, but, nevertheless, has aided its shipping by profitable payment for carrying the mail, by appropriations for maintaining forces of naval reserves and by "admiralty subventions," which are used to encourage the construction of fast steamers that would be of use to the Admiralty in time of war.

If special protection is to be given a country's shipping, there is small doubt that the direct and honest method of granting subsidies is preferable to the method of discriminatory duties. "But why," asks the skeptic, "should *any* special favors be given to shipping?" If the United States or any other country cannot build and maintain its shipping without the subventions from the public treasury, why should a country so circumstanced try to carry its own goods in its own vessels? Would it not be more profitable for it to employ the boats of other nations to carry its imports and exports, and turn its energies and its labor and capital toward the building up of industries in which it has, as compared with those other nations, a real advantage? In short, why try to build up a national merchant marine if you can save capital and labor by hiring other countries to do your carrying for you? Such is the general outline of the free trade or *laissez-faire* argument in its particular application to the problem of maintaining merchant shipping.

Now, so far as purely economic considerations are concerned, it must be admitted at once that the *laissez-faire* argument is fundamentally sound. On purely economic grounds there is no more reason why every nation should try to do all its own carrying any more than why every man should make his own clothes. Purely economic considerations, however, never had governed national policies, and in the case of the merchant marine there may be good reason why they should not.

Adam Smith, the great apostle of free trade, made a special exception of the encouraging of such domestic industries as are necessary to the defense of a country. He held that the old restrictive British navigation acts were "not favorable to foreign commerce or to the growth of that opulence which can arise from it." But, he added, "As defense, however, is of much more importance than opulence, the act of navigation is perhaps the wisest of all the commercial regulations of England." The merchant marine, as the recent experience of the world has shown, is of incalculable value as an adjunct to the navy in time of war. The movement for the limitation of armament, culminating in the Conference on Limitation of Armament in Washington, has succeeded in limiting the construction of ships designed primarily for fighting purposes — a fact which may make it necessary for the nations of the world to depend more and more upon the possibility of impressing their merchant vessels for naval purposes in case of war, and justify the adoption of a carefully worked out policy of subventions to them. Be it noted, however, that these considerations do not justify a policy of indiscriminate bonuses. If the national merchant marine is to be viewed as an auxiliary or secondary navy, it is clear that it should be planned with that purpose, among other things, in view. Thus, following the British example, it may be wise to subsidize certain types of boats of exceptional speed, or of exceptional cruising radius, or with other especially desirable qualities.

It is idle to suppose, however, that in the long run a nation can build and maintain a merchant marine by subsidies or subventions in the face of economic disadvantages. Moreover, no nation has ever yet succeeded in monopolizing its own trade for its own ships. The absurdity of such a purpose appears clearly when we remember that, since in international commerce cargoes are taken from a port of one country to a port of another country, and since it is hardly practical to transship goods at sea, it follows that on the average a large part of the trade of the world must be carried in "foreign" ships. No country can expect to monopolize the carrying of its own trade, for the carrying of a country's own trade involves an equal amount of the carrying of the trade of other nations. It is sometimes urged that the prosperity of a country's foreign commerce is bound up with the prosperity of its merchant marine; that a country must carry its own foreign trade, if its foreign trade is to thrive. In general, and except under special conditions, there is little truth in that doctrine. The ships of the world, and especially the tramp steamers which are free to go from port to port in search of cargo, will come to carry the trade of any country which has trade to offer. Temporary combinations among owners of shipping may lead to temporary discriminations in rates or in facilities against the trade of particular countries, but competition, especially among the owners and masters of tramp steamers, is too intense to make discriminatory actions of any particular significance.

Discriminations on the part of other governments or on the part of the grouped business interests of other countries are, however, met with frequently enough, so that it is well for any government to retain in its own hands the power of effective retaliatory discrimination. A weapon which it may be unwise to use for purposes of offense may nevertheless be wielded with effect in the defense of national interests.

There is one new economic factor in the world's shipping situation which may prove to be of much greater advantage to the merchant marine of the United States than artificial discriminations or subsidies could possibly be. Cheap coal of good steaming quality, conveniently accessible to tide-water, has, as we have seen, been of the utmost importance in developing and maintaining the prestige of Great Britain's shipping. But within recent years there has been a marked trend toward the use of petroleum instead of coal to furnish power for steam vessels. With respect to petroleum, the advantage is with the United States rather than with Great Britain.

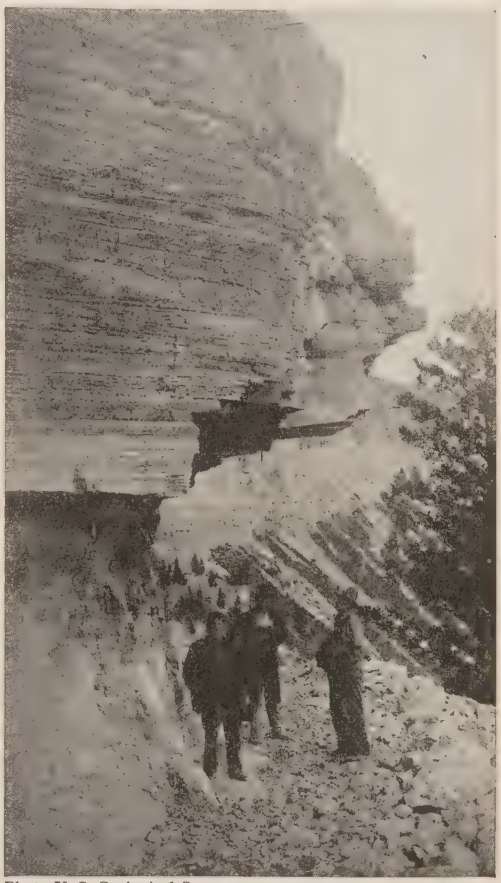


Photo U. S. Geological Survey

RICH OIL SHALE OUTCROPPING IN COLORADO

Many of the new ships have been constructed to use petroleum instead of coal and many of the older ships, especially the larger and faster passenger vessels, have had oil-burning apparatus installed. Petroleum saves labor. For every ten overworked stokers on the coal-burning vessel, the oil-burning ship uses in its boiler room only one fireman, employed at clean and

comfortable work. Forty per cent of the bunker space is saved, so that more space is available for cargo. Time is saved in port, because the taking on of fuel oil is a relatively simple task. Even more important is the increased cruising radius of the oil-burning ship. It does not have to stop so frequently at bunkering stations, and its profitable voyages may be planned with less reference to the necessity of reaching bunkering points at frequent intervals.

Especially with the internal combustion Diesel engine is the superior efficiency of oil fuel shown. Oil-burning steamers have advantages over coal-burning steamers, but the internal combustion engine requires even fewer men — and those all skilled engineers — and has greatly increased cruising radius. E. N. Hurley, at one time chairman of the United States Shipping Board, tells of two ships of the same tonnage which went around the world leaving Europe, around Cape Horn, and returning via the Suez Canal. One, a coal-burning steamer, stopped for coal fourteen times, and burned 8500 tons. The motor-ship burned 1500 tons of oil, and had sufficient capacity to carry oil for nearly all of the voyage, but, as a matter of fact, earned some money by using some of its tank capacity to carry oil cargo from one port to another. The steamer made the voyage in 300 days, the motor-ship in 236 days; the coal cost $41,000, the oil cost $13,000; the coal steamer carried 14 stokers, the motor-ship none. There was a saving of 70 per cent in fuel, 20 per cent in time, and the cargo carried by the motor-ship was 15 per cent larger. The time saved on the voyage and in port resulted in an important reduction in freight charges, on account of the smaller interest and depreciation on the cost of the ship.

From the point of view of immediate cost, the advantage seemed to be wholly with petroleum, as against coal. This, in the normal course of events, should give an advantage to the United States somewhat comparable to that which Great Britain has enjoyed in the past through her coal. For the United States produces about two-thirds of the world's petroleum.

Furthermore, it is likely that the largest additions to the world's output will come from the countries bordering the Caribbean Sea and the Gulf of Mexico, although the Persian and Mesopotamian fields promise to be important producers.

Any doubt with respect to the wisdom of the transition from the use of coal to the use of oil must be based upon consideration for the welfare of the future. The United States has thus far used less than one per cent of its magnificent coal reserves, but it is estimated that it has used up something like 40 per cent of its reserves of petroleum. Furthermore, the demand for petroleum for other uses — for automobile operation, for tractors, for lubricating oil, as fuel for locomotives, for industries and even for heating — is growing rapidly. If the United States were forced to depend upon its own domestic supplies of oil, they would last for hardly more than twenty years. Already it is importing oil from Mexico, as well as from other countries. Oil can undoubtedly be extracted from the oil shale of Colorado and Wyoming, as well as from bituminous coal, but only at an expense so large that it would lose its advantages over coal. W. S. Jevons, the great economist, told Great Britain how transient must be the prosperity based upon the exploitation of natural assets like coal. With even more force the same thought presses in upon us when we contemplate the future of the world's oil supplies. Is that wonderful natural source of energy to be used up in a generation or so, or is it to be conserved for those uses in which its advantage over other fuels is most decisive? Is it wise to purchase a few brilliant decades of maritime prosperity by robbing future generations of so important a part of nature's inheritance? May it not be wise or even necessary to restrict the use of fuel oil to the navy and to such merchant vessels as must have high speed and long cruising radius? And may it not also be wise to insist that fuel oil shall not be burned in steamers, but shall be used only in the more economical internal combustion motors? No more important problem of economic policy faces the American people.

THE REIGN OF THE GHOST

How the Fiercest of Primitive Races Came
To Respect Human Life and Property

THE ORIGIN OF FUNDAMENTAL LAWS

IN any kind of stable government there must be a respect for human life and a respect for property. The central authority, or the community at large, may possess all the property, and may exercise a tyrannical power over the lives of the people; yet the individual member of society must not rob or slay his neighbors. All this is obvious; but the origin of the ideas of ownership and of the sanctity of human life is very far from being obvious. The matter was not plain when Herbert Spencer completed his masterly survey of the evolution of human society, and it is only within the last few years that our younger leaders of science have been able to throw a strange and yet clear light on it.

We have already seen how the art of government was developed by a class of magicians who ruled the people by superstitious fears and practices. Brute force did not play in the early forms of society so important a part as is commonly thought. For we have found in tracing the origin of kingship that superstition has often been more potent than reason or armed ambition in building tribes into nations.

And what we now aim at showing is that superstition has often done more than laws or material punishments to establish in the mind of primitive and savage man that respect for human life and for private ownership without which the world would have been ruled by successful murderers and thieves. It is patent that the more violent instincts of uncivilized man had first to be repressed, before anything larger than the family clan came into existence. But it is not easy to see at a glance what power there was available to this end.

Primitive and savage men have at times even hunted their fellow-creatures for food; and there was no constraining force outside of their individual selves which could repel them from murder and robbery. Indeed, it must have been the easiest thing in the world to find an opportunity for slaying even a relative out of anger or jealousy or ambition. The ancient hunters were often brave and daring men, who risked their lives almost daily in the pursuit of game. Some of them, even in the Old Stone Age, were the practical masters of the earth, and the huge and ferocious cave-bear was their favorite food. Men such as these had to be forced to respect each other's persons in the wildest outbursts of bad temper, while living under conditions of great hardship with practically no social machinery to enforce the respect for human life.

As a matter of fact, the work now done by our highly organized police system was then performed by the murdered man himself. It may have been a dangerously facile thing to kill his body, but that only set his ghost free to haunt the slayer. Primitive man certainly believed in ghosts, and he seems to have had the same superstitions concerning them as the modern savage. Beside the body of his dead he placed a store of food and an armory of weapons for use in the spirit land. He believed that animals had spirits as well as men, for he has also left, in the caves in which he dwelt, pictures and carvings of the beasts he hunted. They are apparently drawn for magical purposes, one representing men disguised as animals going through some strange ceremony.

The impressionable and unsettled state of the minds of savages

A great deal of evidence of this sort has lately been discovered among the most ancient of the existing remains of early men. It all goes to show that primitive man had much in common with the modern savage in the matter of beliefs. At one time it used to be argued that no just conclusions with reference to the evolution of human society could be drawn from the study of existing savage races. It was contended that the modern savage had very likely developed in a direction entirely different from that of the chief primitive tribes of prehistoric times.

It is highly probable that some of the customs and beliefs of modern savages are more complicated than those of primitive men, but, on the other hand, there are many indications that the savage has preserved the main lines of very ancient ways of thinking and feeling. His mind is almost as much a relic of the Age of Stone as the flint weapons he uses in hunting and warfare. Moreover, we are often able to discover, in the traditions of the most civilized of present nations, vestiges of prehistoric institutions which can only be understood when they are compared with forms of government still obtaining among savages.

Now, in regard to the origin of the idea of the sanctity of human life, we must remember that the savage imagination is very impressionable and remarkably childish. Everything that a man of the lower races does not clearly understand frightens him, and there is very little that he really does understand. There are good grounds for assuming that he is amazingly susceptible to hypnotic suggestion. Many savages can actually be killed by witchcraft. If they learn that the customary magical rites for destroying them have been performed, they will become ill and die — simply through their wildly extravagant and imaginary fears. This psychological fact has more bearing on the origin of certain human laws than have all the theories about social contracts and myths concerning the earliest legislators.

Modern sentiment about ghosts a survival from the terror of earlier times

Greater than the fear of the living magician is the dread of the ghost of a dead person. To the savage way of thinking, the soul of a baby that dies soon after birth may become a very harmful spirit, continually haunting the whole tribe, and bringing disaster upon all its undertakings. The fear of ghosts is hardly extinct among ourselves, and it is practically universal among savage people. All ghosts are dreaded, but the spirits of slain men are especially an object of terror to their slayers and to the community.

In ancient Greece, even an involuntary homicide was exiled for a year, so that the anger of the wraith of the dead man should have time to cool down. Orestes, the son of Agamemnon, killed his mother because she enticed her husband to a bath on his return from Troy, and there had him slain by her paramour. Orestes' act was an act of justice, but according to the Greek view it did not save him from punishment. The ghost of his mother pursued him wherever he went, and at last maddened him. In this wild and tragic legend is faithfully reflected the ancient Greek conception of the fate which overtakes the murderer at the hands of the ghost.

Homicides banished to protect community from visitation by the spirit of the dead

It was more in self-defense than out of any consideration for the slayer that a Greek community compelled him to depart from the country. This is evident from the provisions of the law. In the first place, the homicide had to keep to a certain road when going into banishment. It would have been hazardous to let him stray about the land with an angry and dangerous spirit dogging his steps. In the second place, if another charge was brought against a banished man-slayer, he was allowed to return and plead in his defense. He was not, however, allowed to set foot on land. He had to speak from a ship which was not permitted to anchor, and the judges decided the case while sitting or standing on the shore.

The ghostly revenges feared from murdered men by savage people

Obviously, the intention of this rule was literally to insulate the slayer, lest by touching the earth, even indirectly through the anchor or the gangway, he should blight everything by a kind of electric shock. The ghost-ridden man was full of a sort of effluence of death, and any contact with him might kill the crops or spread some plague.

Seeing that the most intelligent and cultivated race of the ancient world, the Athenians, were governed in their respect for human life by superstition, we cannot wonder that many savage and barbarian peoples are still obsessed by similar ideas. Among the Omaha Indians a murderer whose life was spared by the kinsmen of his victim had to observe certain rules for two to four years. He had to walk barefooted, and never eat warm food, nor speak loudly, nor look around him. He had to tie his robe tightly about him, and keep his hands always close to his body. Even if his hair was free, the ghost might get hold of it. Nobody would eat with him; and when the tribe went hunting, he was compelled to pitch his tent a quarter of a mile from the rest of the people, lest the ghost should raise a high wind which might cause damage.

When the spirit of a murdered man is thus feared by everybody, it is natural it should be especially dreaded by those against whom it may be conceived to bear a grudge. For example, when the relatives of a murdered man among the Yabim of New Guinea accept compensation instead of avenging his death, they must get one of their family to mark them with chalk on the forehead. If this is not done, their dead kinsman is sure to punish them for not avenging him. Perhaps they will suffer from toothache, and end by losing all their teeth, or the ghost will frighten and drive away all their pigs!

Practically everybody in a savage community who dies a violent death becomes a public danger. The temper of the ghost is naturally soured, and it is ready to avenge itself on the first person it meets. It is too angry to discriminate between the innocent and the guilty. So general offerings of food are made to the spirit by the tribe, in the hope of propitiating it.

Laying the ghosts of slain men by blood-stained ritual

In some places, however, an attempt is made to frighten the ghost away. Papuan villagers assemble for some nights after a murder has been committed, and beat drums and shriek to drive away the spirit of the dead man. Many Indian, Zulu and Fijian tribes take similar measures to protect the community against the angry ghost. The Bhotias of the Himalayas perform an elaborate ceremony for transferring the spirit of the dead man to an animal, which is beaten by all the villagers and driven away. Having thus expelled the ghost, the people return with songs and dances to their village.

The shedding of blood can often be expiated by some magical rite. This usually consists in sacrificing some animal, presumably to the ghost, and washing the slayer in its blood. The Greek mode of purifying a homicide was to kill a sucking pig, and wash in its blood the hands of the guilty man.

The penitence and purification of the victors in savage warfare

The Cameroon negroes smear all the relatives of the slayer and the slain with the gore of an animal; and practically all savage races perform some ceremony or act to lay the ghosts of slain men. Of course, men killed in battle are just as dangerous spirits as men murdered in the ordinary way. Something has always to be done to evade the terrible results of a victory, or the souls of the defeated host will sweep down and destroy by magic their conquerers. The methods adopted in the defense against the spirits of the slain are too numerous, and often too ghastly, to be fully related here. Acts of penitence lasting for six months are performed by some Indians; the Basutos wash themselves in running water with the help of a magician, and follow this with the sacrifice of an ox.

Several tribes in various parts of the world shave their heads, a custom which the ancient Greeks at one time followed. Many savage warriors shut themselves up in their huts, and their wives and friends shun them. Others live for a time a hermit's life in the forest, being exiled just as Orestes was, so as to concentrate the malignity of the ghost on themselves, and prevent it from attacking the whole community. Some Australian natives, on returning home from a victory, turn when their camp is in sight and perform an excited war-dance. This is really a fight with the spirits of the slain men; and the warriors fancy they can tell by the sound made by their shields whether they have defeated the ghost, or whether the ghost has struck them a mortal wound from which they will soon die. Professor J. G. Frazer has collected a vast store of practices of this kind, which will be found, by readers interested in the subject, in his book "The Golden Bough".

How dread of ghosts tends to preserve life in overcrowded China

Nowhere is the fear of ghosts so salutary an influence in enforcing a respect for human life as in the vast commonwealth of China. As is fairly well known, when a Chinaman is suffering under a grievous wrong, he will often commit suicide and convert himself into an angry ghost, in order to wreak in death that vengeance on his oppressor which he could not exact in life. In another way the general welfare of the Chinese race is promoted by the dread of ghosts. Life is so hard in many parts of the country that married peasants are often strongly tempted to restrict the size of their families by female infanticide. It is the fear that the souls of the murdered little ones will gruesomely punish the parents which prevents the Chinese farming classes from unnaturally restricting the growth of population.

So, finding that superstition has originally done more than any system of laws to keep men from shedding each other's blood, we shall not be surprised to discover that it has also clearly helped to maintain the respect for private property.

As even animals of intelligence display a sense of proprietorship, the old theory that individual property was not recognized by primitive men seems to be contrary to fact. When we see that the claim to exclusive possession is understood by a dog, so that he fights in defense of his master's clothes left in his charge, it becomes impossible to suppose that mankind in its very lowest state was devoid of the ideas and emotions that give rise to private ownership.

The use of ghostly fears in the preservation of private property

On the other hand, private property in land is very unusual among savage tribes. The hunting-ground is held in common, and when the hunters develop into farmers the tradition of communal ownership often grows more strong and binding. The tribe depends so much on coöperation in both warfare and agriculture that its territory usually remains a great common possession, binding all the members together. It is to the fruits of individual industry that the sense of private ownership appears first to attach. The problem which the savage has first to solve is to prevent other persons from stealing the weapons and instruments which he has slowly and laboriously fashioned. A Bushman, for instance, sometimes picks up the arrows lost by another hunter in the chase. It would seem natural in the circumstances for him to profit by his find, for he would thereby be saved the trouble of arrow-making. As a rule, however, the Bushman is at pains to return the lost objects to the rightful owner. "How do you know to whom the arrows belong?" a Bushman was asked. He pointed to some marks on the shaft.

Marks and designs of a similar kind are found on weapons of the Old Stone Age in Europe, and it is fair to assume they were made for the same purpose, probably of a magical nature. Every savage regards himself as something of a magician; he may not have those powers which are possessed by the chief wizard of the tribe, but he is confident that he can protect his private belongings.

Beneficial action of the taboo superstition in preserving individual belongings

This is done by a magical rite, which has various names. In Polynesia it is known as *tapu;* in Melanesia the system is known as *tambu;* in the Malay Archipelago it is commonly termed *pomali;* and in Madagascar it is called *fady.* The rite is widely practised in Africa, and it has been imported by negroes to the West Indies; it also obtains at the present time among native tribes of America, and in many other parts of the world. The South Sea term for it has been naturalized among us as "taboo", but as used by us this word does not convey fully the original meaning, nor have the same significance.

In the opinion of the natives, the effect of tabooing a thing is to endow it with magical energy which renders it very dangerous to anybody except the rightful owner. Before the natives came into contact with Europeans, the system of taboo worked with amazing success. The most valuable articles might, in ordinary circumstances, be left for any length of time to its protection, in the absence of the owner, without fear of being molested by any of the other members of the tribe.

A MEDICINE-MAN IN CENTRAL AFRICA

The patient is lying on a mat in the sun, the medicine is in the waterbuck's horn resting on the injured hip, the medicine-man is decorated with white pigment, and by his gymnastic exercises is supposed to be chasing away the disease.

Reproduced by permission from Mr. Alfred J. Swan's book, "Fighting the Slave Hunters in Central Africa", published by Seeley & Co.

If anyone wished to preserve his clothes his house, his crop, or anything else, he had only to taboo the property, and it was safe. To show that the thing was tabooed, he put a mark on it. Thus, if he wished to use a particular tree in the forest to make a canoe, he tied a wisp of grass to the trunk; if he left his house, with all its valuables, to take care of itself, he secured the door with a piece of flax. The place at once became charged with a sort of curse, ready to fall on any interferer. It meant at least a very bad sickness.

Moreover, the curse could be made retrospective. If a man went to his plantation, and saw that some cocoanuts had been stolen, he ran about shouting imprecations on the thief. As the thief believed in the magical effect of the curse, it naturally troubled him, and worked on his highly impressionable imagination. Men and women have been known to fall dead on learning that, merely by mistake, they had eaten some food which had been previously tabooed by their chief. This astonishing susceptibility to hypnotic suggestion is a characteristic of many of the lower races which must always be kept in mind when studying their apparently foolish institutions.

The means by which these institutions are worked seem childish and foolish because they are connected with a condition of mind away from which many — but not all — members of highly civilized communities have now developed.

The hard, clear reasoning power which is the priceless possession of the highest races has enabled the best minds among them to escape from that extravagant power of non-rational suggestion which was called into play by the primitive chief to control the individual members of his tribe.

The importance of savage susceptibility to hypnotic suggestion

They have lost, perhaps, the responsiveness to suggestion on which mental healers rely, but this loss is more than compensated by a gain in self-control and concentrated reasoning power, which is one of the greatest of all the forces in modern civilization.

To understand the savage and the primitive man, we must attempt to see things from their strange point of view. We must admit that witchcraft can be efficacious when it is used on persons extremely liable to hypnotic suggestion. When we have admitted this, we shall perhaps see that black magic was not altogether a malign and misdirected force in the earliest stages of the evolution of human societies. We are not concerned to maintain that the general good effects procured by the various forms of witchcraft were sufficient to outbalance the numerous and long-enduring bad effects.

The system of taboo kept primitive man in an organized state of society

Millions on millions of human lives have been destroyed in the course of the ages through superstition. Yet we must not allow our feelings of disgust to blind us to the fact that the strange, unreasonable and impressionable mind of primitive man has sometimes turned to good use the forces of evil that worked in it.

"The New Zealanders," said A. S. Thomson, in 1859, "could not have been governed without some code of laws similar to the taboo." Warriors submitted to the fear of magic who would have spurned with contempt the orders of men. It was certainly better, having regard to the absence of law and the fierce character of the people, that they should be ruled by superstition rather than by brute force. It was the system of taboo which kept them in an organized state of society. In a masterly work, "The Origin and Development of Moral Ideas", Dr. Edward Westermarck has shown that superstitious fears have done much to restrain mankind from theft and murder, from anarchy and immorality. Keeping to our special topic, we can, in conclusion, cite only a few cases out of many given by Dr. Westermarck in his interesting book.

In Ceylon, when a person wishes to protect his fruit-trees, he hangs some grotesque figures round the orchard, and dedicates it to the evil spirits. No native will then dare to touch the fruit. Even the owner himself will not venture to use it till the charm has been removed by a priest. Some Indians simply surround their plantations with a single cotton thread, and it is believed if any trespasser broke the thread he would die. The negroes of Africa are usually afraid to rob each other for fear of being killed by fetish magic.

Breton belief in the efficacy of the death-vow in avenging wrongs

In modern Brittany the present writer found that many of the peasants believe that a thief or a perjurer can be made to die of a disease lasting for several months by performing the death-vow. In order to see how this was done, we asked one of the rustic wizards to help us to avenge ourselves on an imaginary man for an imaginary wrong. We were conducted at midnight along the banks of the Jaudy, near Tréguier, to a patch of ground on which there had once stood an ancient shrine to St. Yves. The wizard made us kneel down, and then knelt down beside us, and recited some prayers in the Breton tongue. Then in bad French he made the vow, asking us to repeat it after him: "Thou art the little saint of truth, and we vow to thee so and so. If he is right, condemn us" — the plural is always used — "if we are right, condemn him, and make him die within the appointed time."

Instead of making the vow to St. Yves, the Breton peasants sometimes make it to the image of death, carved in the form of a skeleton in some of the old parish churches. It is probable that the latter figure, in the early days of Christianity, inherited the cult of the Celtic god of death worshiped throughout Gaul and Belgium and Britain and Ireland in the belief of pagan days.

In conversing with M. Anatole Le Braz, the Breton student of folklore, a few years ago, we told him of our identification of St. Yves and the figure of death and the Celtic god of death, with reference to the still living superstition of the death-vow. M. Le Braz said that the same idea had occurred to him. Space does not permit us to give all the evidence we have collected as to the identification, but we may say that we have found various indications of the connection between Celtic deities and modern practices in ancient Irish records, medieval Welsh literature and Celtic folklore.

All this goes to support the statement made by Professor J. G. Frazer some thirty years ago in an article in which he maintained that "the system of taboo played an important part in the evolution of law and morality". The system was not the creation of a legislator, but the gradual outgrowth of a mass of superstitions, to which the ambition and avarice of chiefs and witch-doctors afterwards gave an artificial extension. In serving the cause of avarice and ambition, however, superstition also served the cause of civilization. It fostered ideas of the rights of property, of the sanctity of human life, and of the marriage tie; and, in the course of time, these ideas grew strong enough to stand by themselves, and to fling away the crutch of superstition which in earlier days had been their sole support.

We shall scarcely err in believing (concludes Professor Frazer) that, even in advanced societies, the moral sentiments, in so far as they are merely sentiments and are not based on an induction from experience, derive much of their force from an original system of taboo. Thus on the taboo were grafted the golden fruits of law and morality, while the parent stem dwindled slowly into the sour crabs and empty husks of popular superstition, on which only the most foolish minds in modern societies are still content to feed. After all, the most baseless superstition of the lowest savage is no worse in character than those silly fancies of certain wealthy women and men which are exploited by fortune-tellers and clairvoyants. The savage, at least, gets out of his superstitions some useful rules of life which go to make him obedient to the best impulses of his childish nature.

The wild, strange fancies of the savage mind have sometimes done more to promote the general welfare of primitive races than any selfishly rational ideas could have done. Clear, precise reasoning power is only an instrument; it can be misused. If a man employs it entirely to selfish ends, he may be more rational in a way than a superstitious savage, but he is less social, less human. He sins against the light.

Photo E. Torday

A BAPENDE MAN OF THE CONGO FREE STATE WEARING A GHOST-MASK

The savage, living in spiritual darkness, manages to obtain some good guidance in life from the most childish notions.

The system of taboo was not, of course, the only force which made for the development of the rights of private ownership. Very interesting is the later process by which land, once held in common by the tribe, came to be split up among separate owners. A great deal in the current discussion about the nationalization of the soil is based on exploded theories of the origin of the private ownership of land.

FIVE HUNDRED SQUARE MILES OF GLISTENING SALT

Photo George L. Beam

GREAT SALT BEDS AT SOLDURO, UTAH, EIGHT MILES WIDE AND SIXTY MILES LONG

WHERE OUR SALT COMES FROM

From the Primitive Salt-Lick to
the Modern Electric Soda-Factory

THE INDUSTRY THAT LED TO COMMERCE

SINCE mankind turned from a wandering to a settled life, the obtaining of salt has been the most important of industries. Only where savages retain the brutal habit of drinking the fresh blood of the animals they kill is it possible for them to do without common salt. There are few things more distressing than salt hunger, and one of the most dreadful forms of torture the Chinese practise is to provide a prisoner with ample nourishment but insufficient salt. Purely vegetarian peoples have from prehistoric times fought their way to the sea in order to obtain salt. This cause of migrations has recently been discerned from a study of the movements of the black races of Africa. In recent times, inland African negro tribes have been known to prize salt above gold; for a handful of it a slave girl could be bought. Mungo Park related that some negroes had a way of referring to an extremely wealthy man as one who "seasons all his food with salt" — the most extravagant form of luxury they could conceive. Apparently it is almost as bad as lighting a pipe with a ten-dollar bill. We know how highly esteemed salt was in Biblical times by the sanctity of the "covenant of salt".

There are thus many reasons for supposing that salt was the earliest article of general barter. Food, clothing and other necessities of life the warring tribes could obtain for themselves, but inland peoples were obliged to trade for salt with seaside nations; and so commerce on an international scale originated. The rarity and dearness of salt in ancient times were, of course, due to difficulties of manufacture. It is plentiful enough in sea water. The oceans contain 4,800,000 cubic miles of salt, which would cover an area as large as the United States with salt crystals more than a mile and a half deep. There are also 325,000 cubic miles of rock-salt beds known to exist on the earth. And it is mainly from the brine pits and mines of this apparently small extent of solid beds of salt that the demands of the world are satisfied. In the United States the supply is practically inexhaustible. Not only can we take care of our own needs indefinitely but also those of the rest of the world for a long time to come.

With the progress of science and civilization, salt has grown in importance and value. For, as soon as it was known to consist of forty parts of the silvery metal sodium — which is as soft as wax, lighter than water, and caustic — and sixty parts of chlorine — a yellowish-green, heavy, irritant gas — chemists began to use it in new ways. From it they made carbonate of soda, bicarbonate of soda and caustic soda, together with hydrochloric acid and bleaching powder. Glass-makers and paper-makers, soap-makers, dyers, bleachers and wool-scourers depend now on chemicals made from common salt. From an old salt mine in Prussia there is obtained much of the potash used in various manufactures and employed as a fertilizer by the principal agricultural nations. So it will be seen that the salt industries have increased in value with the progress of civilization. Common salt is still a vital necessity for almost every race of mankind, and those that do not use it are compelled to obtain the salt they need by drinking fresh blood.

There are three principal kinds of salt — sea salt, rock salt and brine salt. That made from sea water is of the most ancient use. Even animals are acquainted with the salt-licks, formed in certain shallow bays by the evaporation of brine in the hot sun. In prehistoric times, men began to make by the seaside artificial ponds, into which they could at will let in a flood of sea water that would evaporate in the sun and leave a deposit of the tiny white crystals that were useful in preserving meat and seasoning foods. From these primitive salt-beds were slowly developed the scientific salterns now used in Italy, Spain, Portugal, France, Austria and at Syracuse, New York; and continued in more old-fashioned forms along the shores of all the continents.

A saltern usually consists of a number of condensing-beds, arranged in a slope, through which the brine flows gradually, increasing in density as it approaches the last condenser. From this it gravitates into the crystallizing-beds, or is pumped up to them. It often happens that an arm of an estuary, an inlet, or a silted basin can be banked off from the sea. This forms an admirable brine reservoir, where much of the suspended matter in the water can settle, while a slight process of evaporation goes on. A flood-gate connects the reservoir with the sea, and a pipe carries the clear water from the reservoir to a shallow pool fronting the condensing-beds. Usually an open channel connects this pond with the first row of condensing-beds.

Each bed has a very large surface, with a depth of only a few inches, so that the drying action of the air and the sun may take effect quickly. In the first series of beds the brine only thickens. But as it runs in gutters to the second and lower crystallizing-ponds, the salt begins to form in a crust on the liquid. The saline incrustation of the crystallizing-pond is broken up and collected in small heaps on the embankments by means of rakes. The sea salt, however, is at first very impure, the impurity consisting chiefly of chloride of magnesium. This is got rid of by forming the smaller heaps into big stacks, and letting them stand for a long time with a covering of straw. The straw keeps the rain off, and the moisture of the air slowly dissolves the chloride of magnesium, and separates it from the mass.

CRYSTALLIZING-BEDS WITH WORKERS RAKING IN SALT THAT HAS BEEN DEPOSITED

Formerly, the lye, or mother-liquor, that remains in the last crystallizing-ponds was allowed to flow back as waste into the sea. But this thick brine is now often run into a shallow pond of beaten clay about an acre in extent. It contains a considerable quantity of valuable chemicals, especially sulphate of soda and chloride of potassium, one of which can be extracted by cold and the other by heat. There was a time when the lye was exposed in winter for the sulphate of magnesia to be deposited, and then pumped up to a covered reservoir, and preserved until the following summer, when the chloride of potassium was obtained by evaporation. But this method is too costly and troublesome to be used today.

Nowadays artificial cold is applied to the waste liquor, and the chemicals are extracted from it at once. It is reckoned that 250 acres of salterns in a warm, southern climate will produce ten thousand tons of sea salt. But a spell of bad weather between March and September, when the evaporation is being carried on, sadly interferes with the production. For the process so entirely depends on the sun and the moon that in a wet season scarcely any salt is formed.

COLLECTING THE PILES OF SALT FROM THE EVAPORATION-PANS AT BENGHAZI, TRIPOLI

At Hayling Island, near Portsmouth, England, the manufacture of salt from sea water was carried on long before the Norman Conquest. St. Augustine praised this salt for its excellence. . Until a few years ago it was still made during the four summer months. The beds varied in size up to a quarter of an acre, and in favorable weather the sea water in them became brine in seven days. It was then pumped by windmills into pits, from which it ran into iron pans. It was boiled for twelve hours, and skimmed to remove impurities. The crystals were shoveled out, hot and wet, into wooden trucks, from which the mother-liquor ran off through holes in the bottom.

HARVESTING SALT WITH A PLOW FROM DEPOSITS IN THE CALIFORNIAN DESERT

It is thus seen that the concentration of sea water for salt by solar evaporation is a rather uncertain industry except in the warm dry climates. The cost of fuel and labor, together with the fact that sea salt, is apt to be of inferior quality as well as coarse, prohibits evaporation over a fire. Our country, rich in rock and brine salt, has made comparatively little use of the salt found in the sea itself, although the sea salt plants of California are still of interest to the tourist of the Pacific Coast.

The way in which deposits of rock salt are worked depends very much upon the locality, the depth of the bed, the price of fuel, the rate of wages and so on. In some places it is a mining operation, and it is carried on by means of shafts and horizontal galleries. The most famous of salt-mines is that of Wieliczka, in Poland, which probably contains the largest and the purest deposit in the world. The bed is said to extend for five hundred miles, with a breadth of twenty and more miles, and a depth of 1200 feet. Being an underground city, hewn in the course of ages in glistening rock salt in the heart of the earth, the Wieliczka mine is a most surprising monument of human labor. It lies below the quiet Carpathian valley of the Vistula. The Cracow railway runs some miles away, in order to prevent the dangers of vibration.

Hundreds of years of patient human toil have honeycombed out of the solid rock salt an entire city at various levels. It consists of an intricate maze of winding streets and dim, scintillating alleys, of pillared churches, diamond and ruby staircases, restaurants, railroad stations, shrines, statues, monuments and a thousand other wonders — all rough-hewn in the sparkling rock salt crystals which, when lighted by electricity, pine torches, magnesium flashes or thousands of candles, blaze like a world of precious stones. Elevators descend to this fairy city, but there is also a long staircase cut from the solid rock, which flashes ruby and emerald at every step.

About two thousand men work night and day in the underground city in eight-hour shifts. The mine has been worked since 1251, yet its resources have scarcely been touched, so immense are they. What distinguishes the Polish miners from all others is their love of art. Far from being depressed in their strange underground city, they have, for some hundreds of years, given a great deal of their spare time to carving huge monuments and innumerable statues out of the glittering rock. Emulation must have been the secret of all their gigantic art work. It seems that no sooner was the first shrine chiseled from the salt, the first statue carved, than succeeding generations of miners were fired with zeal and determined to exercise their genius for sculpture. The salt-hewn cathedral of St. Anthony dates from the seventeenth century, and was planned by a pious foreman. The miners carry their religion with them to the depths of the earth, and strange and touching services are held in the rock salt churches. Many of the men are musicians, and they have their own orchestra for festive occasions.

Some 300 feet away from the cathedral is a magnificent cavern cut from the rock. It is over 300 feet long, and towers to a height of 190 feet. Along its flashing walls are great statues of Knowledge, Labor and other symbolical figures. At one end is a rock salt throne of state, formerly kept for the use of the emperor of Austria-Hungary and the imperial archdukes. Whenever an old working is exhausted and closed, or a new street opened in the subterranean city, the event is celebrated by a dance in the great hall. Hundreds of picturesquely clad peasant women — wives, sisters and sweethearts of the underground workers — take their partners into the cavern, where shrill pipes and soft flutes and violins make merry music as the couples whirl in wild Slavonic dances.

What adds to the strange beauty of this subterranean city is the illumination.

DRAWING THE SALT USED IN CURING FISH, ETC., WHICH HAS SETTLED IN THE BRINE-PAN

The immense halls, restaurants, churches and other public buildings are lighted by great chandeliers of salt crystals. One of them is 10 feet in diameter and 20 feet high, containing about two hundred and forty candles. There is a central railroad station, where all the little traffic lines of the city of salt meet. It is three centuries since it was made the center of the town. Many of the principal streets converge upon it. The lines are narrow gauge, the little cars being drawn by Polish ponies, most of which have never been on the surface, and are born blind. The platform of this great central station has seating-room for four hundred persons.

On holidays its cafés are crowded with visitors from the upper world, who take their meals to the wild music of the miners' orchestra that echoes and reverberates strangely through the dim and yet sparkling streets.

There are also waterways in this weird city. In many places the saline lakes are from 20 to 30 feet deep, and over them ply ferry boats, holding a couple of dozen passengers. The boats give access to the remote and very ancient parts of the mine, such as the Stephanie Grotto, where rock-hewn statues of medieval saints arise out of the dense salt water, girt and enshrined, as it were, by curiously beautiful salt stalactites and stalagmites. The lakes are fed by subterranean springs, and they are a source of peril to the miners, for they sometimes rise suddenly and drown the workers in the lowest galleries. The inhabitants lead, indeed, a hazardous as well as a hard life. Great masses of rock salt, often weighing hundreds of tons, fall now and then in avalanches from the domed roofs of the streets or the ceilings of new chambers.

Besides floods, fires and falls of rock — all of which catastrophes put on a ghastlier horror in the depths at which they occur — there is another serious danger of violent explosions from the gas that accumulates in newly excavated galleries. Yet for centuries these disasters have not daunted the thousands of inhabitants of the strange city of salt. Children are born and christened in the underground caverns, and, growing up, they continue the work of their fathers. Extending along the Carpathian Mountains for five hundred miles, the rock salt out of which the churches and halls of Wieliczka are built is mined at many other places — in upper Austria and Hungary, in Tyrol and Styria, in Transylvania and Wallachia. While this great bed of salt in Poland is the largest known, there are many similar smaller ones in other lands. Many of them made their presence known to man centuries ago through salt springs that rose from them.

Geologists are not agreed as to the exact manner in which these great beds of salt were formed and buried deep in the earth. Perhaps the most commonly accepted theory is that the areas on which they rest formed at one time the bed of large, shallow ponds near the ocean and so situated that the salt water could flow into them but to no great depth. Constant evaporation by the sun left these great deposits of salt, and subsequent geologic changes buried them under many feet of stone and earth. Quite recently another explanation of the formation of salt-beds has been advanced in connection with the mines of Louisiana, which differ from the others in being close to the surface and which are famous for their remarkable purity, their product containing $99\frac{1}{2}$ per cent of sodium chloride. The theory advanced is as follows. It seems that the older rocks in the Mississippi region all slope toward the south at a much greater angle than does the surface of the ground. Water entering fissures of these rocks in Arkansas, for example, would flow south and find itself thousands of feet below the surface when it reached the Gulf of Mexico. It would naturally become very warm as compared with surface water and would easily dissolve soluble substances like salt. If, now, a break or point of weakness occurred in the upper beds of rock, the water would work its way to the surface after the manner of water in an artesian well. But as it rose it would cool and some of the salt held in solution would crystallize and gradually a mass of solid salt would be formed. The strength of a growing crystal is known to be sufficient to overcome almost any resistance, and it has been claimed that such growing crystals of salt have lifted part of the Gulf Coast at least 3500 feet thick. With brine supplied to the salt mass from below, crystallization naturally takes place mainly on the bottom, especially after the column has attained considerable dimensions. The resultant movement upward of these great salt masses accounts for the proximity to the surface of the Louisiana mines. This theory, while plausible, has not been accepted by all geologists, and we shall probably have to wait some time before we know with certainty how these valuable deposits were formed, possibly differently in different cases.

THROUGH THE BED OF AN ANCIENT SEA

THE CHIEF SHAFT OF THE SALT MINE OF SLANICU, IN ROUMANIA, BY WHICH EIGHTY THOUSAND TONS OF SALT ARE RAISED TO THE SURFACE EACH YEAR

In America rock salt is produced by deep shaft mining in the eastern, central and southern sections of the United States. There are salt mines in Michigan, New York, Kansas and Louisiana. Salt is also made, still, from springs and salt lakes by solar evaporation but the greater part of the industry is based on buried deposits. In Kansas four rock salt mines are found near the central part of the state. The earliest work in this district was done about 1890, while the Louisiana mines date back to 1862. The Michigan field, near Detroit, produces a very good grade of salt, which only needs grinding to prepare it for table use. The vein lies about 1150 feet below the surface, and until very recently this was the deepest salt mine in the world. Central New York, now boasts the deepest shaft ever sunk for salt mining and, incidentally, the most up-to-date mine equipment yet installed. This shaft, which is on the shore of Cayuga Lake, one of the "finger lakes" left by the receding glacial cap, is 23 by $11\frac{1}{2}$ feet and 1500 feet deep. The vein is 60 feet thick and of excellent quality. Over one million feet of hickory and white oak have been used in the underground construction, besides vast amounts of concrete.

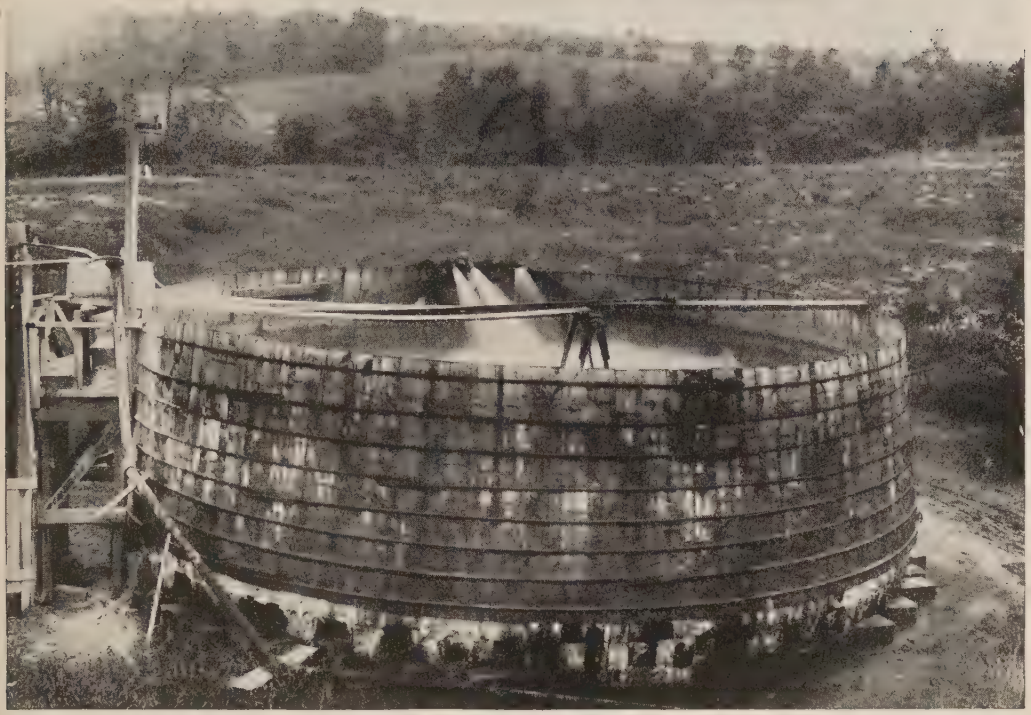
Many difficult problems arise in connection with salt mining. In Michigan, for example, underground water and quicksand were encountered, making it necessary to resort to the clever scheme of running refrigeration pipes through the troublesome section, thus keeping the sand and water frozen solid until the shaft was concreted.

Salt "licks" and springs are found in nearly all the states of our country. Those of southern Illinois were worked by the French and Indians in 1720, and it is recorded that the famous Kentucky salt springs were known and used before 1790. One of our most remarkable salt works is at Salton, California. A marshy lake, 28 feet below the level of the sea is continually fed by numerous springs in the surrounding foothills. This lake is rich in brine and its waters, evaporating quickly under the warm sun, leave deposits of almost pure salt varying from 10 to 20 inches in thickness. On account of the extremely high temperature in this dry climate, only Mexicans have been able to do the work of collecting and shipping the hundreds of tons of salt which have been daily taken from the lake.

In the United States most of the salt is obtained from the brines by some sort of artificial evaporation. With the exception of a few subterranean lakes, or pockets of brine, the deposits are in the form of rock salt and must be dissolved by water led down through long pipes. A well similar to that used for crude oil is first drilled and a heavy steel casing of about 10 inches in diameter inserted simultaneously with the drill. This casing serves to keep out water and materials which would impede the progress of the drill. When the drill has reached bed-rock and the casing has been driven home, the lower part of the well may be finished with a smaller drill which descends to the bottom of the salt vein. Then a smaller 6-inch casing is lowered to the bottom of the well and an effective joint made between the two pipes. Thus the finished well consists of a line of tubing 10 inches in diameter down to the solid rock and 6 inches in diameter below the rock level. Two pipes of smaller diameter and arranged concentrically are now inserted to carry water and compressed air. Fresh water is forced down to the bottom and gradually the dissolving process on the salt-bed begins. It should be noted in this connection that large quantities of pure water are demanded in the salt-making business, as well as in many other industries. This accounts for the presence of many of our salt plants on the inland lakes and rivers.

In some countries the use of the brine process has caused much trouble because of the dissolving of the salt-beds which were fairly close to the surface. There is no chance to support the undermined ground as in the case of salt mining, and, as a result, a gradual, sometimes a sudden, settling of the surface has occurred not unlike that caused by an earthquake. In our own country the salt vein is usually found at some depth and covered with great thicknesses of rock, which form a very sure support for the surface material.

THE BRINE PROCESS



PUMPING UP A SALT BED

Water is forced down to the buried layer of salt through one pipe and the brine so formed is forced up another or uptake pipe. The brine is here seen flowing from an uptake pipe into the settling tank.

Courtesy International Salt Co.

LOOKING DOWN ON EIGHT OF THE SETTLING TANKS

Many of the impurities separate out before evaporation.

The pressure in the down-flow pipe causes the brine to ascend the uptake pipe. The brine which ascends is a rather heavy liquid and must be relieved, not only of the water which has been added to allow it to pass through the pipes, but of several undesirable chemicals as well as sand and dirt. For this reason it is allowed to remain for about 24 hours in settling tanks and where chemicals may be added if necessary to hasten the separating action. The next step in the refining process is one of artificial evaporation. This is generally accomplished in one of three ways, although no two plants agree in all the details of the process. The first is the old "kettle" method in which the evaporation is carried on in iron kettles of about 4 feet diameter, set in rows of 16 to 25 over a flue leading from the furnace to the chimney. The brine is delivered to the kettles through a pipe which runs the length of the rows. After a time it begins to crystallize on the sides of the kettle. It is then raked out, placed in a perforated basket and set over the kettle where it continues to crystallize and drain back its moisture into the kettle. This method has been generally abandoned in this country because of lack of economy in fuel consumption and because only one grade of salt can be produced, and that rather poor.

In Michigan and New York, the two states that produce three-quarters of the country's salt, two other methods are usually found working in combination. This is done because there is a desire for more than one quality of salt and neither method alone affords much variation. From the settling tanks the brine is led either to "grainers" or to "vacuum-pans." The "grainer" is simply a development of the "kettle" method, while the idea of using vacuum-pan evaporation was borrowed from the sugar refining industry. All of these processes are based upon the fundamental idea that substances which crystallize can be obtained in a state of comparative purity by allowing the crystals to form in the mother liquid. They also make use of the fact that the higher the temperature of crystallization, the finer the crystal formed.

The grainer is simply a wooden or steel trough, 12 to 18 feet wide and 90 to 150 feet long, in which steam pipes are suspended a few inches from the bottom. The brine flows in to a depth of about 14 inches, a level automatically maintained by a float valve. The foaming crystals sink to the bottom of the trough, whence they are slowly pushed to a sloping drain, and shortly after on to a conveying belt by means of an automatic feathering rake. The grainer salt is of the variety used for pretzels or in certain packing processes where the finest grade of salt is not needed.

The "vacuum-pan" process is extensively used because of the excellence of the product and because it is very economical. The name is really a misnomer, as the illustrations show. The "pan" is not a pan at all but, in the form most generally found, consists of two cones set base to base on a short cylindrical section, in which are many hundreds of copper flues, open at both ends. The brine is run into the pan till it fills the lower cone and that part of the cylindrical section that carries the tubes. Steam is then allowed to enter through various openings into the middle section, and at the same time the air is pumped from the brine. This, of course, lowers the boiling point of the latter so that it is unnecessary to supply as much heat through the steam as is required in a system which evaporates at atmospheric pressure. The cost of fuel, of pumping the air, of upkeep on the various members of the system will determine the most economical pressures and temperatures at which to operate.

As the brine boils in this pan it will give off vapors which must be withdrawn to some sort of a condensing chamber, otherwise the influence of the air pump would soon be counteracted. In a multiple effect pan such as shown in the illustration the pans are connected in series so that the vapors from one pan are used to heat the adjacent one, the air pressure gradually dropping through the series. In this particular installation the pressure on the brine varies from 14 to 28½ inches of mercury on a certain day in February when the condensing water was very cold.

A VACUUM-PAN PLANT

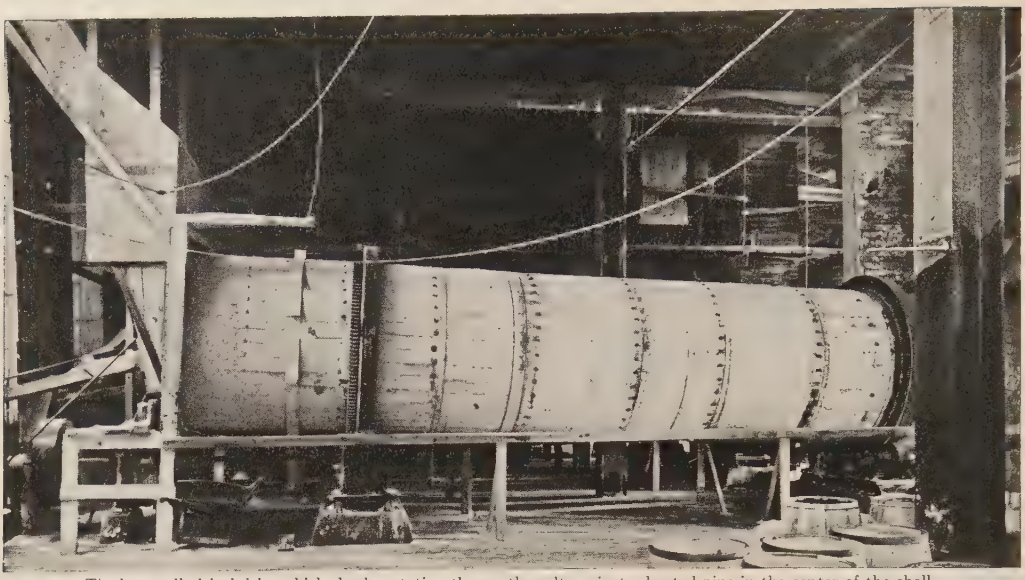
INTERIOR OF A VACUUM-PAN PLANT

The floor is rather less than halfway up the pan. The steam belt surrounds the pan just above it.

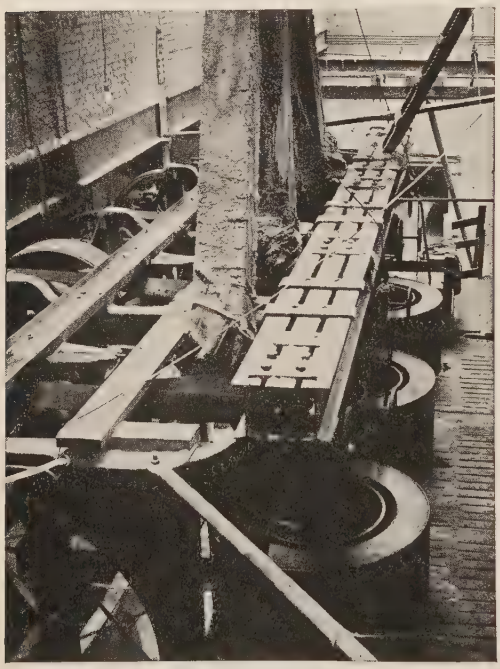
Courtesy International Salt Co.

WHAT THE PANS REALLY LOOK LIKE

It is difficult to obtain a good view of a vacuum-pan installation when in operation. This illustration shows a "quadruple effect" plant taken after a fire had burned away the surrounding building.



The long cylindrical drier which slowly rotating throws the salt against a heated pipe in the center of the shell.



DRYING THE SALT

Looking down on a battery of centrifugal driers. In these the salt is rotated at a very high speed and centrifugal action drives the water out of the salt, the latter being restrained from flying outward by strong screening.

In this way the steam is made to pass successively through all the pans, and if all works well in a four-pan outfit, one pound of steam may be made to evaporate $3\frac{3}{4}$ pounds of salt water. The scheme may be roughly compared to the use of steam in a quadruple expansion steam engine.

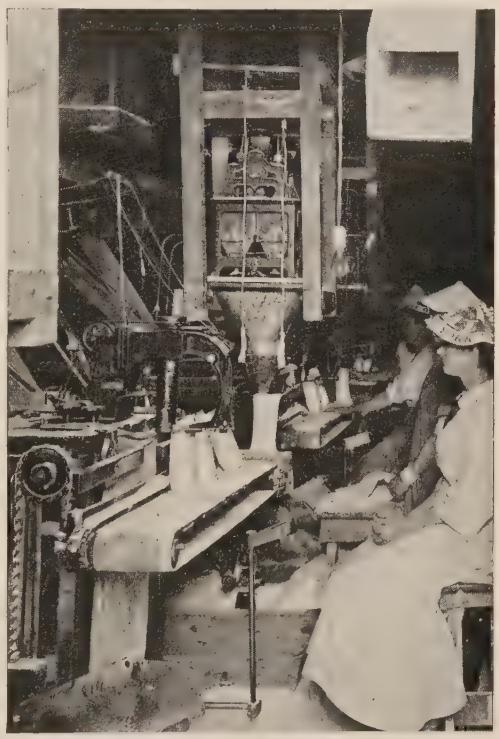
It should be added that this method of refinement is not without its difficulties. Experts must watch each change in pressure and temperature and regulate the system with judgment. A few minutes of inattention may cause hours of shut-down.

The salt as it comes from the grainer or vacuum-pan still contains some moisture which must be removed before it can be stored or packed for shipment. The endless belt in the case of the grainer, and the endless chain elevator in the case of the vacuum-pan, deliver the salt to centrifugal driers where most of the remaining moisture is removed. The salt may be now stored in heaps on the floor of the curing room, or it may pass at once through a long cylindrical drier filled with baffle plates which force the salt to drop on a central heated pipe which takes away what little moisture still remains. Much of the finest salt undergoes a month's curing process as it lies stacked in the curing room. These mountainous heaps of salt are often a source of danger to the workmen as they shovel it into the barrels or bags. On many occasions the undermined, overhanging cliff suddenly collapsed, bringing death to the buried workmen. To obviate this danger the holes are drilled with an electrically driven auger near the base of the cliff, thus bringing about a gentle collapse which could be guarded against.

The packing of salt into barrels or large sacks is still largely done by hand. In the case of smaller sacks and cartons, automatic machinery is employed which weighs the desired amount of the finished product for each container.

In considering the uses of salt one naturally thinks of it first as a food. The finest table salts, made in the latest type of vacuum-pan, are not only sifted to a flour-like fineness, but are treated in such a way as to prevent caking in the shaker. All of the commercial salts carry with them certain deliquescent salts which will draw an amount of moisture from the air. To overcome this tendency various moisture absorbers are used, principally very small amounts of cornstarch or calcium phosphate. It is possible by the use of steel-jacketed mixers to so combine these materials with the salt that there is no appearance of dustiness in the finished product. Large quantities of salt are now in use in refrigeration plants where salt brine is used as a cooling medium. Hides, meat, fish, butter and many other products use their share of the 7,000,000 tons of salt our country produces annually.

Perhaps the real cause of the increased output during recent years has been the tremendous growth of many of our chemical industries which require salt as a raw material. A shortage of materials usually imported as well as a greater demand for the exportation of certain chemicals, the great development of the hydro-electric power plant enabling more efficient use to be made of the electric furnace, and the general expansion in all our industries help to explain it. As has been mentioned, salt consists of the two chemicals, sodium and chlorine. It is possible to separate these and, by another combination, produce the household necessity — soda. A Frenchman, Leblanc, invented a method of accomplishing this result many years ago. His scheme required the use of oil of vitriol for treating the salt. It was not long before a Belgian, Solvay, invented a similar process, using ammonia instead. The later developments improved the Solvay process to such an extent that the Leblanc method would have been discontinued had it not been for the fact that two other very valuable products, hydrochloric acid and chlorine, were also produced by it. In this way the materials that were at first by-products became the leading products. Bleaching powders all depend for their action on chlorine, so a new industry was established. On the other hand no successful means has yet been discovered for obtaining bleaching powder from an ammonia soda plant. At Syracuse the Solvay process is in use and many sodium compounds are produced in great quantities.



PACKING SALT BY MACHINERY

These semi-automatic machines fill and sew up forty bags per minute.

At Niagara Falls, now the center of the chemical industry of the world, an electric system of dissolution has been used for several years. When a strong current of electricity is passed through a brine solution, the chlorine escapes as a gas, and being led through lime chambers forms the chloride of lime or bleaching powder. The sodium by another chemical reaction may be converted into "caustic" soda or sodium bicarbonate, sodium nitrate or other valuable chemicals.

THE GREAT PIONEER OF EVOLUTION

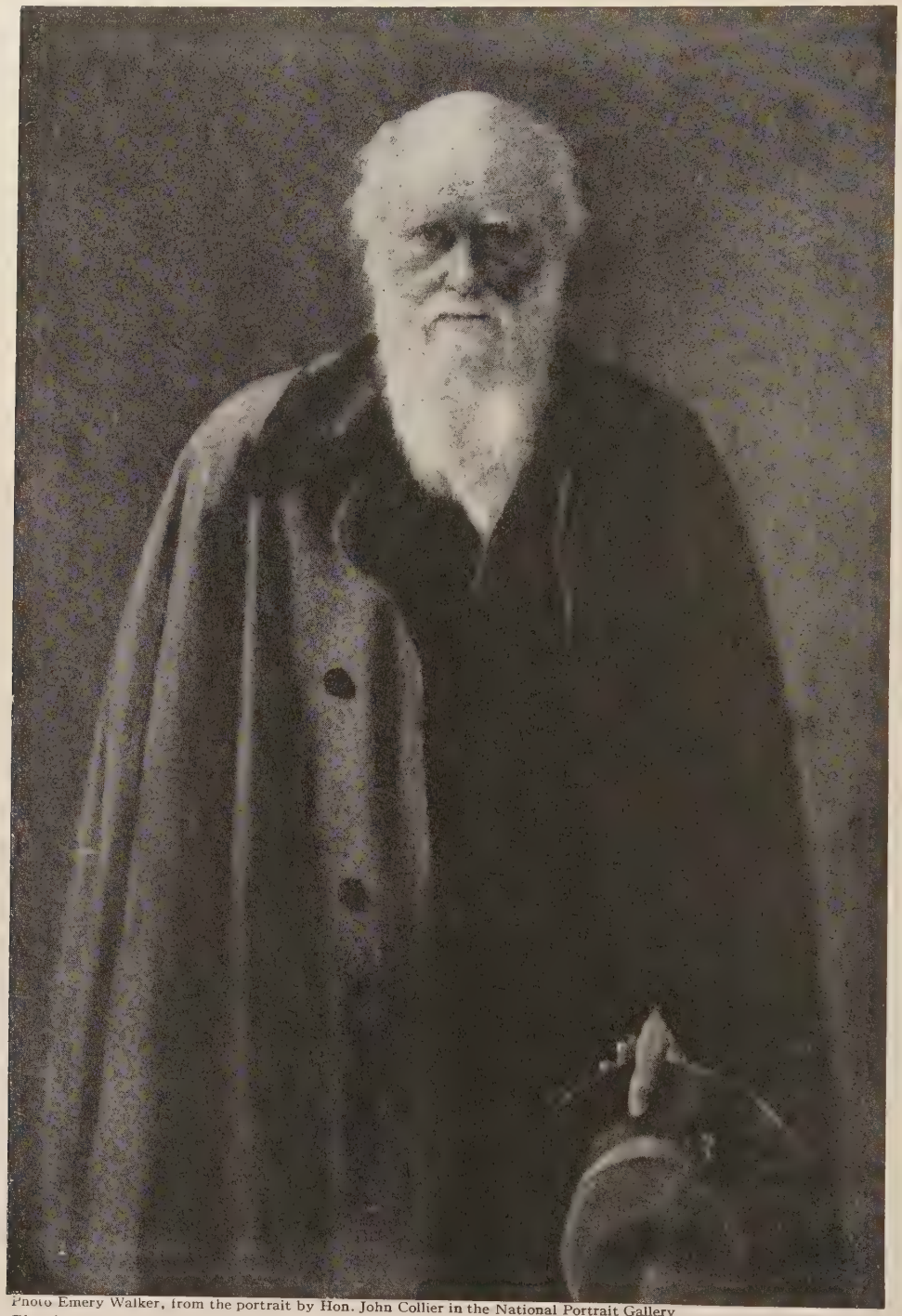


Photo Emery Walker, from the portrait by Hon. John Collier in the National Portrait Gallery

Charles Darwin, author of "Origin of Species," the man whose works have aroused the most fierce and unremitting controversy in the history of thought.

NATURALISTS AND BIOLOGISTS III

CHARLES DARWIN — THE MAN WHO SHOOK THE WORLD OF THOUGHT
ERASMUS DARWIN — THE FIRST POET OF ORGANIC EVOLUTION
PAUL EHRLICH — A GREAT INVENTOR OF CURATIVE POISONS
DANIEL GIRAUD ELLIOT — FIRST NATURALIST IN THE OLYMPIC MOUNTAINS
JEAN HENRI FABRE — THE FRENCH ENTOMOLOGIST AND POET OF SCIENCE
GUSTAV THEODOR FECHNER — A PIONEER OF EXPERIMENTAL PSYCHOLOGY
SIMON FLEXNER — LEADER IN SCIENTIFIC MEDICINE
SIGMUND FREUD — THE FOUNDER OF PSYCHOANALYSIS

CHARLES DARWIN
The Man Who Shook the World of Thought

CHARLES ROBERT DARWIN was born at Shrewsbury, England, on February 12, 1809. His father, Dr. Robert Darwin, the son of Erasmus, was a successful physician. His mother, the daughter of Josiah Wedgwood, died when he was eight, and in this year he began going to a local school. "By the time," he says, "I went to this day-school my taste for natural history, and more especially for collecting, was well developed. I tried to make out the names of plants, and collected all sorts of things — shells, seals, franks, coins and minerals. The passion for collecting which leads a man to be a systematic naturalist, or virtuoso, or a miser was very strong in me, and was clearly innate, as none of my sisters or brother ever had this taste."

In 1818, Darwin went to "Dr. Butler's great school in Shrewsbury", and stayed there for seven years. His master condemned him as entirely dull, and his own mature verdict, not written for publication, is as follows — "Nothing could have been worse for the development of my mind than Dr. Butler's school, as it was strictly classical, nothing else being taught, except a little ancient geography and history. The school as a means of education to me was simply a blank. When I left the school I was for my age neither high nor low in it; and I believe that I was considered by all my masters, and by my father, as a very ordinary boy, rather below the common standard in intellect."

From his useless school Darwin went to Edinburgh to study medicine, but with little success. He never began dissection, and he could not draw, two disadvantages which he describes as "irremediable evils" for his life-work.

But Darwin was not destined by nature for medicine, and soon he and his father agreed that he should become a clergyman, so he left Edinburgh for Cambridge, where he found that he had actually forgotten even the Greek alphabet. As he tells us, "My time was sadly wasted there, and worse than wasted." He shot and hunted, and rode and dined, "and we sometimes drank too much." Collecting beetles beat hunting, driving and dining for Darwin at Cambridge. One of his sporting friends, seeing him at his beetles, told him he would one day be a fellow of the Royal Society, "and the notion seemed to me to be preposterous." At Cambridge he read Humboldt and Sir John Herschel, and in 1831 he went as unpaid naturalist on the voyage of the *Beagle*, which he describes as "by far the most important event in my life".

For five years the young naturalist observed and recorded, observed and recorded; and soon after his return home — in July, 1837, to be precise — "I opened," he says, "my first notebook of facts in relation to the 'Origin of Species', about which I had long reflected, and never ceased working for the next twenty years."

In 1839, Darwin married his cousin, Emma Wedgwood, a fact worthy of note, for from these cousins there sprang the family which includes the late Sir George, Sir Francis, Horace and Leonard Darwin, all notable men. He was a devoted husband and father. No one who has any vestige of feeling for beauty of character should fail to read the chapter of reminiscences, in Sir Francis Darwin's life of his father. His children adored him. His devoted wife tended him unfailingly throughout the cruelly harassing nervous dyspepsia which never left him. This alone made his life and work possible: "For nearly forty years he never knew one day of the health of ordinary men, and thus his life was one long struggle against the weariness and strain of sickness. And this cannot be told without speaking of the one condition which enabled him to bear the strain and fight out the struggle to the end."

He loved dogs; indeed, he had a feeling for every living thing, and personified them, one and all. Says his son: "I used to like to hear him admire the beauty of a flower; it was a kind of gratitude to the flower itself, and a personal love for its delicate form and color. I seem to remember him gently touching a flower he delighted in; it was the same simple admiration that a child might have." Sir Leslie Stephen, comparing Dean Swift's observations on servants with those of Darwin on worms, says: "The difference is that Darwin had none but kindly feelings for worms." These facts are interesting when we remember the purely mechanical theory of living creatures which has been erected upon Darwin's writings, and is known as "Darwinism."

The writings themselves are implicit in the whole of modern biology, and no discussion of life in general, or of any of its aspects, can now be written without constant reference to them. Here, therefore, we merely note, for form's sake, the publication of the "Origin of Species", in 1859; "The Descent of Man", in 1871; "The Expression of the Emotions in Man and Animals", in 1872, among several works of less importance.

This man, whose works aroused the most fierce and unremitting controversy in the history of knowledge, was himself as gentle as one of the flowers he loved. He never entered into controversy himself, though he found doughty champions in Huxley, Haeckel and others.

What Darwin called "natural selection" as an explanation, *in part*, of adaptation is the true Darwinism, which Darwin himself taught. This doctrine stands today, so long as no more is piled upon it than its author gives us warrant for. Darwinism is but one of the many attempts to explain the particular influences which produce variation among animals and plants. Although biologists generally admit such — hence some sort of organic evolution or transformism — they are nowise in accord on the factors which cause it. Today the theory of natural selection is deemed inadequate to account for the facts of variation. Hence we have finally abandoned the ingenuous notion of the nineteenth century that Darwin had closed any chapter in biological theory. It is to his lasting credit that he boldly opened many, but he closed none.

He was a supremely great observer, but not strictly a thinker. Though he was a student of life, from first to last, he never framed or seemed desirous of framing any ideas as to the nature of life, which is, after all, the essential problem of biology. He tells us that his mind soon became lost when he embarked upon abstract conceptions. But, though his work is used as the great argument against Design, and though the opposition between Paley and what is called "Darwinism" is absolute, he once recorded his "inward conviction that the universe is not the result of chance."

This great man, morally and in all essential qualities of mind truly admirable, the very exemplar for all time of what the student of nature should be, a man whose daily life and character are a sufficient illustration of the impotence of "Darwinism" to explain the supreme phenomena of Life and Mind, died on April 19, 1882, and was buried in Westminster Abbey near the remains of Sir Isaac Newton.

ERASMUS DARWIN
The First Poet of Organic Evolution

ERASMUS DARWIN was born at Elton, Nottinghamshire, England, on December 12, 1731. He was graduated in medicine at Edinburgh, and soon became a very successful practitioner in Lichfield. But we do not remember him as a doctor; he was essentially a man of science, though his contemporary reputation was that of a poet. Today we do not find any of the essentials of poetry in "The Loves of the Plants," though it is written in meter, and abounds in classical metaphors and mythological allusions. The poem, which is the first part of his stilted and elaborately fanciful "The Botanic Garden" (1789), became famous and was translated into French and Italian. It contained numerous suggestions as to protective mimicry and other features later a part of the elaborated theory of the evolution of plants. The only feature of this poem which interests us is the fact that it reveals, in the grandfather, exactly the same love of and interest in living creatures which we find in the grandson. This sympathetic observation also led Erasmus Darwin to the opinion that, even in vegetable organisms, signs of sensation, and even of will, may be found. This view has its own historical interest, for it anticipates, in some degree, Sir Francis Darwin's observations.

But, above all, Erasmus Darwin is to be remembered for his anticipation of the theory of organic evolution. His views were published, in prose, in his revolutionary "Zoönomia" (1794), and "included the belief that all animals have originated from a single living filament; that changes are produced by differences of climate; that all animals undergo constant changes and that many of their acquirements are transmitted to their posterity; that the contests of the males for the possession of the females lead to such results as were afterward stated under the name of 'sexual selection'; that many structures have been acquired as a means of security in a struggle for existence; and that a vast length of time has elapsed since these modifications began."

In "The Origin of Species" Darwin says: "It is curious how largely my grandfather anticipated the views and the erroneous grounds of opinion of Lamarck," but modern students see that he anticipated also much that his grandson himself afterward advanced.

In 1781 Erasmus Darwin went to live in Derby. He was twice married, with very notable consequences, for by his first wife he became the grandfather of Charles

ERASMUS DARWIN

Darwin, and by his second of Sir Francis Galton, thus furnishing very conspicuous illustrations of what his younger grandson, when making the first serious attempt to place the problem of heredity permanently upon a scientific basis, was to call "eugenic marriages".

He died on April 18, 1802.

PAUL EHRLICH
A Great Inventor of Curative Poisons

PAUL EHRLICH was born at Strehlen, in Silesia, on March 14, 1854, and was educated at Breslau, Strassburg, Freiburg and Leipzig, receiving the degree of M.D. in 1878. Appointed assistant in the university clinic at Berlin in 1885, he was tutor in 1889 and professor in 1890. He was a member in 1890 of the

Institution for Infectious Diseases and, in 1896, was made director of the Royal Institute for Experimental Therapeutics at Frankfort. There he has a magnificent institution, specially provided for him, where his astonishing genius and devotion have adequate opportunities. He has had honorary degrees from Göttingen, Chicago (1904), Oxford and Breslau, many orders and decorations, and, with Metchnikoff, the Nobel Prize for Medicine, in 1908. Since then he has made his greatest discovery in practical medicine.

The chemistry of disease, or, as it may well be called, "pathological chemistry", is and has always been the subject of Ehrlich's life vocation. The essential part of the work of Pasteur had been done when he began his researches. He saw clearly from the first, as indeed all serious students did, that the problems of susceptibility and immunity, of death or of recovery, in cases of attacks of the minute parasites which Pasteur had proved to cause disease were essentially chemical. They involved reactions between the tissues of the host and the substances produced by the invading organisms; and if our understanding of disease was ever to be intimate, and effective for the *cure* of infections, we must attack the details of these immeasurably complex chemical reactions. The simpler theories, such as that of Pasteur himself, were clearly inadequate to explain the production of immunity. That state is not brought about by the exhaustion of a special diet which any species of parasite finds in the tissues. It is a positive, not a negative, state; and the key to its production, under "natural" conditions of disease, should enable us to control disease.

This subject of immunity has chiefly engaged Ehrlich's attention, and his collected papers thereon (1903) are the most notable of all contributions to the subject. By dint of much experiment and his chemical genius, Ehrlich was enabled to devise his celebrated "side-chain" theory of immunity, in which he attempted to express, in terms of chemical molecules, the processes by which immunity is gained, and the conditions under which susceptibility, or lack of immunity, exists.

More than a decade has now passed since this famous theory was elaborated, and it still holds the field. It needs, and has received, further elaboration, but it has proved its value in that it has led investigators — above all, its own author — along lines of inquiry that have proved fruitful.

Paul Ehrlich's work has always been directed to definite therapeutic ends. He did important service, when the antitoxin for diphtheria was first obtained, in devising means for estimating its value, and standardizing it so that it could be safely used by the practitioner. Then, several years later, came the discovery by Schaudinn of the minute wavy translucent organism belonging to the "spirilla", which causes syphilis. This offered a new opportunity for Ehrlich's genius. Almost his first research had dealt with the fashion in which living nerve-cells react to the chemical dye known as methylene blue. To the ordinary student of medicine, the microscopist or neurologist, the fact that a given tissue "stains" with a given substance means no more nor less than that *that* is the substance he uses when he wishes to study the tissue in question. Such knowledge is, of course, invaluable, as when a particular combination of stains or dyes enables the investigator to pick out and discover the tubercle bacillus, or some other microbe of almost equal importance.

But to a student essentially chemical, like Ehrlich, the fact that a tissue stains with a dye is a chemical phenomenon. It means that the tissue has certain chemical constituents which are capable of holding on to that dye. Indeed, in such an everyday fact as the dropping of a stain upon a section or culture, Ehrlich saw chemical processes which were closely allied to those of immunity, as he had studied it for many years. The tissue in question was susceptible, so to speak, to the dye that stained it. But this, which was convenient for the microscopist who wished to study the architecture of the tissue, might conceivably have large consequences in another connection. Let us suppose that the tissue in question is that of some deadly disease-parasite. Let us further suppose that we have available some deadly poison, such as

arsenic, which should quickly kill this parasite, as it will indeed kill any form of protoplasm whatever. If we introduce arsenic into the body of a person in whom the parasites dwell, we find that the parasites are unaffected, though the person may be himself gravely poisoned. The parasites are immune to the poison, not because it is not a poison to them, but because it does not enter their bodies.

Let us now contrive an "amboceptor", to use the name and the idea introduced by Ehrlich many years ago. Let this two-handed substance be such that with one hand it can hold the parasite or some chemical constituent of the parasite, while with the other it can hold the poison. This amboceptor will thus serve as a poisoner, introducing the poison to the parasite, which will forthwith die — and the host or patient will live.

To find or make this hypothetical substance was Ehrlich's task. The amboceptor would probably be some dye which was known to stain — because it entered — the bodies of the spirilla; and perhaps this dye, or its essential ingredient, might somehow be made to combine chemically with arsenic. Then this compound might be given to a patient, so as to kill all the parasites in his body, while he himself would be uninjured, for the arsenic would not injure him, but would be all taken up by the parasites, owing to the action of the amboceptor with which it had been intentionally linked.

Such is an account — too simple, for the facts are excessively complex, but still indicative of the principles involved — of Ehrlich's research. Hundreds of compounds were constructed and tried, unsuccessfully, and the six hundred and sixth substance tried was successful. Its chemical name, indicating its construction and constitution, is "dioxy-diamido-arseno-benzol"; it is usually called "606", or "salvarsan".

Ehrlich hoped that salvarsan, or the substance he sought, would effect a "therapeutic sterilization" at a single dose, so that the victim of syphilis, acquired or inherited, might be cured in a few hours, as compared with the two or three years of treatment by mercury.

The effects of salvarsan, properly used, have indeed been almost magical in hosts of instances, but this absolute extermination of the parasites seems to fail of completeness in many cases. Professor Ehrlich was not satisfied and has since discovered another substance of the same type, neosalvarsan, "No. 614".

DANIEL GIRAUD ELLIOT

First Naturalist to Explore the Olympic Mountains

DANIEL GIRAUD ELLIOT, who died on Christmas eve 1915, was the last link connecting modern ornithology with Coues's so-called "Cassinian period" (1855–1858). For over fifty years of a very active life he studied birds, and more recently mammals, and the titles of his publications would fill many pages. In 1850 when he began his study of birds there were but few people who shared his tastes: no Bird Clubs, no Audubon Societies, no American Ornithologists' Union, no museum even in the city where he resided. Nevertheless the germ of the naturalist within him developed. Like Audubon he journeyed to England to further the publication of his monographs, and for wider investigations.

He was born in New York, March 7, 1835, and traveled in Europe, Africa, Palestine and Asia Minor from 1856–1878, later over the greater part of the United States, Canada, Alaska and South America. From 1895 until his death he was honorary and supervisory curator of zoölogy in the Field Museum of Natural History, Chicago. In the interests of this museum, in 1896 he led an expedition into the interior of East Africa, and in 1898 into the Olympic Mountains, in the state of Washington, being the first naturalist to penetrate into that little known range. Member of most of the learned societies of this and other countries, he was decorated ten times by European governments for his labors in natural sciences. He shared with the late Professor A. S. Bickmore the honor of being one of the two scientific founders of the American Museum of Natural History. As late as 1909 he made a tour which included such diverse points as the second cataract of the Nile, Mandalay, Batavia, Hankow and Mauna Loa.

Dr. Elliot is the author of many books, and has contributed several hundred papers to scientific publications in this country and in Europe. His last work — and the most outstanding — is a monograph on the Primates in three large quarto volumes, completed in 1912 when he was seventy-eight years old.

JEAN HENRI FABRE

The French Entomologist and Poet of Science

JEAN HENRI CASIMIR FABRE was born at Saint-Léons, a little commune in the canton of Vezius, Switzerland, on December 22, 1823. His grandparents on his father's side "were people of the soil, whose quarrel with the alphabet was so great that they had never opened a book in their lives; and they kept a lean farm on the cold granite ridge of the Haut Rouergue tableland." In order that his own father might have one less mouth to feed, Jean Henri was placed in his grandmother's care at Malaval, a tiny hamlet some twenty-five miles distant from his home. Here in the neighboring roads "bordered with brambles, in the glades of bracken, and amid the meadows of broom he received his first impressions of nature." When he was seven years old his parents recalled him to Saint-Léons, in order to send him to the school kept by his godfather, Pierre Ricard. "What shall I call the room in which I was to become acquainted with the alphabet? It would be difficult to find the exact word because the room served every purpose. It was at once a school, a kitchen, a bedroom, a dining room, and at times a chicken house and a piggery. What was read at my school? At most, in French, a few selections from sacred history. Latin recurred oftener, to teach us to sing vespers properly. And history, geography? No one ever heard of them." The master knew no grammar but he taught his pupils "sums".

The boy was twelve years old when his father was tempted to the town and led his family to Rodez, there to keep a café. Fabre paid his fees at the local college by serving mass on Sunday in the chapel. He made progress in Latin and when he came to Virgil found "exquisite details concerning the Bee, the Cicada, the Turtledove, the Crow, the Nanny-goat and the golden-broom". But the café was not a success, and the family moved to Toulouse and later to Montpellier, Fabre being at last constrained to leave his studies and earn his bread now as a lemon seller in the market, now as a laborer on the Beaucaire-Nîmes railroad line. Amid these conditions he studied and obtained his superior diploma from the primary normal school of Avignon, becoming assistant in the normal school at Vaucluse. Here at first he reveled in the opportunity to get some order into his vague knowledge of plants and animals. "While a dictation lesson was being corrected around me, with generous assistance from the dictionary I would examine, in the recesses of my desk, the oleander's fruit, the snap-dragon's seed-vessel, the wasp's sting, and the ground-beetle's wing-case." But finding that natural history would not earn bread, he flung himself into mathematics, and passed the examinations for both his baccalaureates and then the two licentiate examinations in mathematics and physical science, in the end obtaining the chair of physics and chemistry at the college of Ajaccio, without having set foot in a lecture-hall except to undergo the ordeal of examination. In Corsica, his intense impressionability to the things of nature was confirmed and increased: "The sea, with its wonders, the beach, whereon the tide casts such beautiful shells, the *maquis* of myrtles, arbutus and mastic trees: all this paradise of gorgeous nature has too much on its side in the struggle with the sine and the cosine. I succumb." Roaming at night along the marshy beaches he contracted a fever which left him so weak that he had to apply for removal to the mainland, whither he returned to take an assistant-professorship in the Lycée of Avignon in 1851. Here he spent twenty well-filled years, yet obtained neither promotion nor increase of pay. Although his duties left him only brief time for outside work, he spent his vacations in observation and research, eight years being devoted to a method for extracting the coloring principles of madder.

During the inquiry he was visited by Victor Duruy, Minister of Public Instruction and Grand Master of the University, who summoned him to Paris, made him a chevalier of the Legion of Honor, and introduced him to the emperor. His processes, however, were taken advantage of by others and Fabre was left with no resource but the sale of his text-books to eke out his narrow income. The jealousy of his colleagues, aroused by the attentions of the great Duruy, and by the popular and much frequented lectures which the naturalist gave at Saint-Martial, rendered life so intolerable that in 1871 he resigned and devoted himself after forty years of desperate struggle, first in retirement at Orange, later at Serignan, to scientific research and writing.

Fabre's many publications can be divided into two groups: one made up of numerous little text-books of introduction to science, intended for the young, the other comprising his doctor's thesis and all the biological memoirs published separately or in the ten volumes of his *Souvenirs entomologiques* (1879–1907), which was crowned by the French Institute. The first great memoir, which inaugurated his definite career, appeared in 1855. It is an investigation into the problem of how the giant Cerceris wasp, the finest of the Hymenoptera, secures the necessary food for its larvæ — fresh and still palpitating with life:

"The insect digs a tunnel in the soil in which she places her eggs and having provisioned the cell with selected game — cricket, spider, caterpillar or beetle — she finally closes the entrance which she does not again cross." Fabre discovered that this game is seized and thrown to the ground, then the wasp plunges her sting into the body, not at random, for that would involve the risk of death, but at determined points, exactly at the seat of those nervous ganglions which control the mechanical movements of the creature, which is thus paralyzed, and will continue "to live for a very long period without taking nourishment. . . . When the hour strikes the hungry larva will find its favorite meat served to its liking."

At the end of the last volume of his *Souvenirs entomologiques*, in a chapter entitled "Recollections of Childhood", Fabre writes: "*A la nuit tombante, le bûcheron se hâte de lier ses derniers fagots. De même, au déclin de mes jours, humble bûcheron dans la forêt du savoir, j'ai souci de mettre en ordre ma falourde. Que restera-t-il de mes recherches sur les Instincts? Apparemment peu de chose, tout au plus quelques fenêtres ouvertes sur un monde non encore exploré avec toute l'attention qu'il mérite.*"

From Le Gros' *Fabre: Poet of Science*, Century Co.
HENRI FABRE

(As night falls, the woodman hastens to tie together his last fagots. In the same way in my declining days, humble woodman in the forest of knowledge, I am anxious to put in order my bundle of fagots. What will remain of my researches on the instincts? Apparently, very little — at the most a few windows opened upon the world still unexplored with the attention which it deserves.) But in spite of this melancholy undervaluation of his life's work, Fabre lived to see it obtain world-wide reputation, both for accuracy of painstaking observation and for marvelous charm of literary style. He died at Serignan on October 11, 1915, at the age of ninety-two.

GUSTAV THEODOR FECHNER
A Pioneer of Experimental Psychology

GUSTAV THEODOR FECHNER was born in Gross-Särchen, near Muskau, in lower Lusatia, on April 19, 1801, and studied at Dresden and Leipzig, where, at the age of thirty-three, he became professor of physics. There, for several years, he worked at galvanism and the relations between electricity and chemistry. Then, owing to trouble with his sight, he was compelled to abandon physical research, and he devoted himself for the rest of his life to psychology. If we are to understand him we must remember that he came to the study of the mind as a physicist, with the training and the mental habits which that involves.

Fechner was an extremely prolific writer, and was publishing fresh volumes well on in his seventies, but his principal work is his "Elements of Psycho-Physics", which was published in 1860. The researches embodied in this book constitute him the true pioneer in that experimental study of psychology by physical methods which is characteristic of Germany.

The great principle of psycho-physics is, or was, that we can reduce the facts of psychology to mathematical statements as we can reduce the facts of physics. It is, in short, an attempt to contrive a physics of the non-physical, which is of the nature of an absurdity. It was based upon a so-called law which is still often called the "Weber-Fechner law"—but which he himself called the "law of intensity". It asserts that the intensity of a sensation increases as the logarithm of the stimulus; or, in other words, that "in order that the intensity of a sensation may increase in arithmetical progression the stimulus must increase in geometrical progression". But, on further inquiry, it has been shown that this law is not absolutely true, and breaks down altogether in a larger number of instances.

Its author was, however, persuaded into the belief that a mathematics of the mind could now be achieved. He declared that there must be a unit of sensation, as there are units of matter, and that any sensation whatsoever must consist of a certain number of such units. Since sensations are at the basis of psychological analysis, it would seem to follow that, by patient application, we should be able to measure all mental processes and, in the long run, write the formula for the production of "Hamlet", for the heroism of a Jeanne d'Arc, or the tenderness of a St. Francis.

But, of course, such hopes were destined to disappointment. Stimuli are physical things, and can be measured, like all other physical things, but sensations are psychical things, and cannot. Each sensation is not a mere aggregation of a certain number of sensory units. Indeed, there are no such sensory units as Fechner postulated.

It would be very natural to suppose that an author whose view of the mind was so astonishingly mechanical should be, in his view of the world, a materialist, but this was far from the case with Fechner. On the contrary, he was a follower of Spinoza, who argued that matter and mind are different aspects of the one reality; and hence he supposed that our measurements of the physical world ought to suffice as measurements for the psychical world. Fechner is therefore certainly not to be ranked as a materialist, and, indeed, he definitely wrote against materialism and its hopelessness. He died in Leipzig, where he had lived for more than half a century, on November 18, 1887.

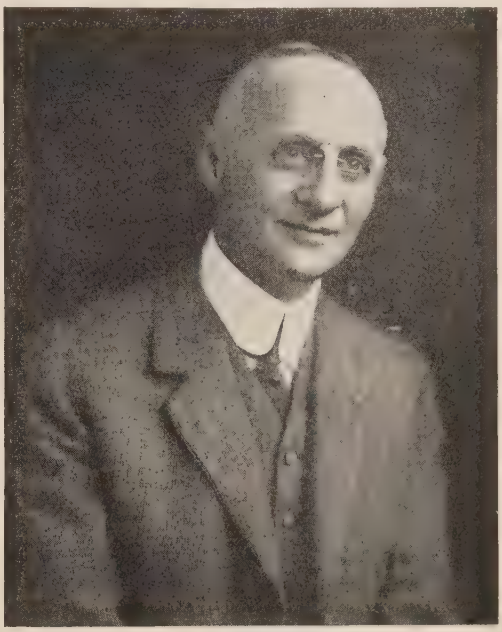
SIMON FLEXNER
Leader in Scientific Medicine

THERE has been no more striking feature in the development of science in the 20th century in the United States than the foundation of various institutes and hospitals where medical research can be carried on under favorable auspices, independent of ordinary practice and administrative duties. As a consequence the science and practice of medicine in America, which for many years was subordinate to or dependent on European thought and research, now enjoy a most favorable position, and there are facilities available here equal, if not superior to, those of any other country, leading in recent years to results of corresponding importance and value.

In this important field no one was more active or fruitful in his work than Dr. Simon Flexner. He was born at Louisville, Kentucky, March 25, 1863, and received his early education at the public schools of that city. Entering the University of Louisville he was graduated with the degree of M.D. in 1889, and straightway devoted himself to further study and experimental research. As a post-graduate student at the Johns Hopkins University Medical School, he came under the influence of Dr. William H. Welch and Dr. William T. Councilman, two famous pathologists, from whom he received a thorough training in pathology and bacteriology. He also studied at the universities of Strassburg and Berlin, but most of his early work was done at the Johns Hopkins University, with which he became permanently associated as fellow in 1892.

His work here resulted in a number of important scientific papers in the fields of pathology and bacteriology. These involved for the most part the relation of bacteria to disease and the method in which the system was affected injuriously by toxic or poisonous substances. He published papers on the pathology of tox-albumin intoxication microörganisms, and also studies on the nature of snake venom, which indicated that such poisons were not dissimilar in their general constitution from bacterial toxins. These latter, of course, acting on the blood to cause its degeneration, serve to develop disease.

Dr. Flexner became an associate in pathology and then associate and professor of pathological anatomy, serving in the latter chair from 1896 to 1899, when he was called to the University of Pennsylvania. About this time the American occupation of the Philippine Islands gave rise to a consideration of important local health questions, and especially in connection with the elimination or control of various epidemic and other diseases affecting the inhabitants. Accordingly, the Johns Hopkins Commission, of which Dr. Flexner was made a member, was sent to the Philippines in 1899 to study tropical diseases. The consequences of his investigations were seen in health measures carried out by the American government. In particular he investigated tropical dysentery, as there prevalent, and by biological studies determined the relation of this disease to the *Bacillus dysenteriæ*, identified and described by Shiga in 1897. These studies, which he elaborated on his return to the United States, indicated that there was a distinct relation between the bacillus of at least one form of tropical dysentery and the microörganism associated with the disease in temperate climates. This connection, as well as the relation of tropical dysentery to infantile diarrhœa, resulted in developing improved methods of treating diseases due to such bacilli.



DR. SIMON FLEXNER

In 1899 Dr. Flexner was called to the University of Pennsylvania as professor of pathology, serving also as pathologist to the university hospital, and in 1901 becoming the director of the Ayer Clinical Laboratory of the Pennsylvania Hospital. At this time, when it was feared that the bubonic plague might secure a foothold in the United States, largely as a consequence of the important work he had done on the commission having to do with tropical diseases, he was made a member of the National Plague Commission and pursued studies in that field.

Then came the opportunity and adequate facilities in which his skill as an investigator and organizer of research could have full scope. In 1901, through the munificence of John D. Rockefeller, there had been organized in the City of New York an institute for medical research where experimental medicine could be carried on under the most favorable conditions, and where a scientific staff could be maintained to prosecute investigations of a special character under competent supervision.

Dr. Flexner accepted a call to become director of laboratories at this Rockefeller Institute for Medical Research, and before entering upon his active duties, in 1903, he studied the various institutes of experimental medicine in Europe, where so many notable achievements had been accomplished. The first important work of the new institute, the laboratories of which were opened in 1904, was in connection with an undue amount of disease and mortality among the babies of the city. It involved a study of milk and milk feeding and was undertaken in coöperation with several hospitals. Then came the even more important question of cerebro-spinal meningitis (often epidemic) which became very prevalent in New York. As a member of a commission to study this disease Dr. Flexner undertook a series of important investigations, resulting, in 1906, in the discovery of an anti-serum. This work involved one of the most brilliant and systematic studies ever undertaken in this field, and early resulted in the discovery that the microörganism causing infantile paralysis was unlike the better known types of bacteria and would have to be developed and identified by new methods. With the coöperation of Dr. Noguchi, an associate at the Rockefeller Institute, Dr. Flexner made artificial cultures of this microörganism, determining its visibility. With the cultures thus obtained he was able to inoculate monkeys and to communicate the disease from one monkey to another, obtaining a serum that was employed successfully for the alleviation of the disease. The serum thus developed was used not only in the United States but in Europe, and in 1909, at the time of the outbreak of an epidemic of cerebro-spinal meningitis, a quantity was sent to France. In this connection Dr. Flexner was made in 1914 a chevalier, and in 1915 an officer of the Legion of Honor.

In 1906, work became more extended by the provision of an adequate building for the Rockefeller Institute built at the foot of 66th Street and the East River in the City of New York. Here an increased scientific staff was assembled and the work of investigation was systematically organized so that in addition to his own efforts, and that carried on by the workers under his immediate direction, other experimenters were placed in a position to carry on valuable investigations. The work later was still further extended by the addition of a fully equipped hospital where the scientific study and treatment of diseases could be carried on directly, with the results of the laboratory tested in actual practice under systematic and thorough control.

Dr. Flexner not only worked in the United States but was a welcome visitor at the Pasteur Institute and similar institutions in Europe. He was a corresponding member of the Academy of Medicine in Paris and of the Medico-Chirurgical Institute of Bologna and the *Société de pathologie exotique* of Paris. In the United States he was a colonel in the Medical Department of the Officers' Reserve Corps of the United States Army, and during the Great War rendered valuable advice and assistance to the hospital and field services. He is a trustee of the Rockefeller Foundation and a member of the board of directors of the Rockefeller Institute for Medical Research of the National Academy of Sciences, and of many American and foreign learned societies.

In 1914 he was elected president of the Association of American Physicians; previously he had been honored with the degree of doctor of sciences from Harvard in 1906, from Yale in 1910 and from Princeton in 1913. In 1907 he received the degree of LL.D. from the University of Maryland, and in 1915 from Washington, Brown and Johns Hopkins Universities.

SIGMUND FREUD
The Founder of Psychoanalysis

SIGMUND FREUD, the founder of the psychoanalytic movement, was born at Freiburg, Moravia, May 6, 1856, graduated in medicine from the University of Vienna in 1882 and specialized in neurology. His doctrines invited the hostility of medical colleagues, but in 1902 he was given a responsible position in the university. His first lectures on psychoanalysis were delivered in 1895, and by 1900 Dr. C. G. Jung of Zurich was practising a modified form of the treatment. The Freudian doctrines gradually made their way over Europe and were received with favor in America. The first congress of psychoanalysts was held in 1908; in 1909 Freud and Jung lectured in the United States; in 1910 a journal in the interests of psychoanalysis was founded. In Breuer and Freud's "Studies in Hysteria" (1895), the new view first appears. Freud's chief works are "Papers on Hysteria"; "Contributions to the Sexual Theory"; "The Interpretation of Dreams"; "Origin and Development of Psychoanalysis"; "History of the Psychoanalytic Movement"; "Leonardo da Vinci"; "Delusion and Dream"; "General Introduction to Psychoanalysis" (1920); "Reflections on War and Death" (1922) — all available in English. The Freudian doctrines and their applications to varied fields of thought and practice constitute a notable contribution to psychology. The subject is represented by a vast literature, including special journals. Freudian ideas have become part of the current thought of modern times, yet a strong opposition, especially to extreme forms of the doctrine, remains.

Psychoanalysis began with a case of hysteria treated by Dr. J. Breuer in 1880–82. The patient developed a paralysis of the right arm, a blurring of vision, peculiar incapacities of speech, states of mental confusion and an aversion to drinking. This last symptom disappeared when, under hypnosis, the patient told of a governess of her childhood whose dog drank from a glass; the disgust at this action and her dislike of the governess brought on the aversion to drinking. The defective vision was similarly traced to a recent scene at the bedside of her dying father. In consulting the time when her eyes were full of tears, she had an enlarged and distorted image of the face of the watch. The paralyzed arm was similarly accounted for. While awaiting the arrival of a surgeon who was to operate upon her father, she fell asleep with her arm hanging over a chair; had a dream in which she saw a black snake; awoke and tried in vain to move her arm, which had become numb; saw her fingers as snakes; tried to pray but could utter only some English rhymes, and for some time could not command German, her native tongue. These momentary incapacities, all experienced under tense emotional strain, became fixed as hysterical symptoms. By bringing these memories from their suppressed retreat in the "subconscious", and thus airing and explaining them, a cure was effected — a process which Freud called "abreaction" or purging. Such treatment of nervous disorders (neuroses or psycho-neuroses) was called "psychoanalysis"; it was based upon the novel idea that the symptoms were conversions or persistences in subconscious form precipitated by emotional shocks (trauma), and that their suppression was a mode of escape from tragic scenes. Yet the patients, typically hysterical, suffer from these disturbing memories sunk below the level of consciousness and converted by their neurotic trends into troublesome and strange incapacities. To resurrect the buried sources of conflict and heal the psychic wounds which, though unrecognized, continue to irritate, and to overcome the resistance to their recall, the hypnotic state was at first used; but later a passive, relaxed confessional attitude ("talking treatment") was adopted. This original case contains most of the essential factors of the Freudian interpretation.

Underlying the Freudian system is the idea of determinism — which holds that the incidents of the mental life — both normal and abnormal, both serious and trivial — are not accidental but condi-

tioned down to their minute details, by causes that escape detection because their source is embedded in the subconscious or unconscious. The next idea is that of *motive;* such thoughts, incidents, symptoms are so buried because they are unpleasant and thus shunned or repressed. They appear to be lost or forgotten; but in reality this type of forgetting or loss of memory (amnesia) has the negative motive of avoiding the unpleasant. The motive appears positively as the Freudian "wish" (or pleasure principle) — a suppressed or unfulfilled desire — determining the trend of thought. It achieves expression in dreams, which picture satisfactions of desires, often unacknowledged and denied an outlet in the actual waking world. There are thus recognized the two orders of "thinking", the one dealing with the real outer world (reality principle), which compels adjustment to its claims (objective), and the inner (subjective) world where imagination may mold things nearer to the heart's desire. The latter is called "phantasy"; romancing, day-dreaming and the dreams of sleep, no less than the symptoms of an hysterical disorder, are ways of escape from reality to phantasy.

Conflict arises between these two orders of forces — the one driving or inclining the individual to thought and conduct in accord with his inner wishes, and the other enforcing the repressions or "taboo" typically imposed by the social code which proscribes certain thoughts or actions as "wrong". Two further ideas are essential: the one that the motive force of the mental life lies deep down in the urges, the great elemental and fundamental instincts with strong emotional tone, that arouse the vital energies by which we live bodily and mentally — and among these Freud gives the major place to the sex-urge and all its comprehensive expressions; the other idea is that the experiences of early childhood are most significant (infantilism); they influence and direct the motives (including the unconscious ones) and the trends of behavior, including abnormal forms of behavior, or neurotic symptoms. Of allied import is the principle of *regression*, which means the strong tendency in the adult to fall back to earlier, childish forms of thought and behavior.

This group of principles constitutes the central structure of the Freudian system: determinism, motive, unconscious, repression, wish, reality, phantasy, conflict, urges, infantilism, regression, all leading to complexes. In these forces and trends, feeling and thought and conduct find their clues. The rest is a matter of combination and amplification; they apply to all phases of the mental life, to types of character, to products of the human mind. The details cover the mechanisms by which the mental (psychic) forces operate. The fields of application are (*a*) a set of mental incidents summarized as "the psychology of everyday life", (*b*) dreams, (*c*) neuroses. Further applications are to such products as myths, which have been called the dreams of the race; to morals; to art, literature, wit; to types of character, and social movements. We thus recognize the principles, the mechanisms and the applications of the Freudian system. Furthermore, the applications — in psychoanalysis as a form of diagnosis and treatment particularly — are presented as the proof or verification of the system as a whole. The Freudian psychology poses fundamental problems: why we feel, think, and act as we do, what manner of personalities we are, under what conditions we live and move, and have our psychic being.

Everyday actions. Freudian explanations are applied to slips of tongue or pen, to forgetting of names or errands, to inadvertent deviation of action from intention. Such slips, errors or lapses reveal a suppressed, half-acknowledged factor, something not wholly accidental, deriving its meaning from a shade of a motive which thus determines the lapse. When a Social-Democratic paper printed "Clown Prince" instead of "Crown Prince", and in apologizing repeated the error; when a patient who was forbidden to call up his fiancée by telephone, in making another call, asked for the wrong number and was given the forbidden one; when, after repeated delay in replying to an unpleasant letter, the

writer sent it without an address, and, when returned, mailed it without a stamp; when a chemist on the day of his wedding went to his laboratory instead of to church (and took the hint by remaining a bachelor for life); when a bride forgot an appointment to try on her wedding-dress (and soon after marriage applied for divorce); when a physician noted that he was more apt to forget visits to non-paying patients than to lucrative ones; when another observed that when he had been smoking too much, he was apt to mislay his pipe; — it is easy to read in these incidents the traces of motive of an inner, deeper, conflicting, partly suppressed (possibly protective) trend, which in an off-guard moment influences thought or action. Similarly, when a speaker says that the persons who understand his subject "can be counted on one finger" (instead of "the fingers of one hand"), we suspect that the lapse has disclosed his vanity. To generalize the principle and conclude that we forget and neglect and avoid the unpleasant, that articles lost may have disagreeable associations, that self-inflicted injuries are not wholly accidental, is hazardous; as other and simpler mechanisms of distraction, confusion, preoccupation, are real and sufficient explanations. No one supposes that owners of lost articles offering large rewards for their return have a suppressed grudge against their possession. It is the partial and occasional factor of hidden motive and the mode of their expression that brings familiar lapses within the range of Freudian incidents, trivial yet suggestive.

Dreams. In dreams the relaxation of the censor is more complete; and the suppressed, unconscious trends have a freer chance for expression; the directive consciousness is in abeyance, yet not wholly. Hence Freud distinguishes between the *manifest* content of the dream, the incidents or story as related, which is derived from recent events, and the *latent* content, which is the true inner meaning in terms of motive, wishes, urges. The dream is a dramatized, condensed and disguised version; the distinctive process by which these mechanisms operate is symbolism. The Freudian dream is typically symbolic. The dream is part of the psychoanalytic technique; a means of discovering in neurotic patients the source of their troubling symptoms and resistances. When extended to dreams in general, the problem is to account in detail for the incidents and their significance as repressed and disguised wishes, employing the dream avenue of expression.

Dream-analysis is so complicated and discursive that an outline can but meagerly suggest the process. A patient, aged 37, dreamed that he was attacked by a man with a dark mustache, using sharp weapons; the dreamer inflicted a wound on the man's left hand; the name "Charles" seemed connected with the man, who, however, changed into a fierce dog, whose head the dreamer split in two by forcibly tearing the jaws apart. The explanation: "Charles" suggested a dentist, Dr. Charles Stuart, who a week before extracted a tooth from the mouth of the patient's wife (manifest, recent source); this dentist wore a beard and did not account for the dread. Next, "Charles" suggested the Stuart kings, and then a former family doctor named Stuart Rankings, who when the patient was five years old had brutally gagged the boy and extracted two teeth, the boy, however, biting the doctor's left hand. (The Stuart "rank-kings" and Stuart Rankings is a verbal play not uncommon in dreams.) The doctor is symbolized by a dog because he was a dog-fancier (also in manner of life a "gay dog"), and had given the boy a fine collie. Thus the true source of the dream is an infantile incident, tensely and disagreeably emotional, which had been buried in the unconscious (latent content). The later elaboration is called secondary and is often responsible for the intricacy of dream plots and incidents.

A young woman dreams that she was walking with her sister and idly playing with a ring, finally coming to a pile of shavings, in which the ring was *accidentally* lost. The explanation: The ring is a "graduation" ring with the date engraved in it, thus revealing her age, which she was anxious to conceal as she was con-

templating marriage. She had often felt that she would like to lose the ring, but could not afford to do so actually, and so completed the wish in dream episode.

The first incident lacks the typically sexual tone which Freud detects in all dreams; and in the second, it is but mildly active. Freud's examples, with rare exceptions, are disguised sex wishes, and proceed in terms of sexual processes. He develops an elaborate series of symbolisms of the sex-organs — one for the male and another for the female — and for all the incidents of sexual approach and consummation. He continues with the development of a "family romance" (the Œdipus complex), in which the son is erotically attracted to the mother, the daughter to the father (Electra complex), involving also plotting in infantile fashion for revenge, murder, replacement of parent. No part of the Freudian doctrines have been more violently opposed as remote and unproven than this. Freud uses this dream material as evidence that the "racial mind", in weaving myths and dramas, follows the primitive, authentic trail of the dream. Because the sexual life is subject to the greatest repression and embodies the strongest urge, is its place in dreams and neuroses directive. How far the dreams of the neurotic regularly reveal such motives and mechanisms is a matter of dispute; their application to normal dreams is still more sharply questioned. Freud admits that the dreams of children are more simple and direct, lacking the symbolic disguise; the same is true of simpler adults, as in the dreams of a marooned expedition in the frozen north on a limited diet, dreaming of rich feasts, and letters from home, and the passing of ships. That other types of dreams occur seems certain; as phantasies dreams find their complement in day-dreams, more subject to conscious initiative and direction. Both are allied to the subjective order of thought, which pervades such products as myths, fairy tales and primitive folk-lore which can also thus be psychoanalyzed or interpreted and reveal a latent symbolic meaning. They are supported by a similar logic, and according to Freud, betray a similar origin in unconscious, partly suppressed desires, finding expression by employment of similar mechanisms. The symbol becomes a characteristic type of (unconscious) racial thinking.

Neuroses. The central concern of the Freudian system is with the origin and nature of the functional nervous disorders or neuroses; the principles of explanation have been set forth in the introductory statement, beginning with Breuer's original case. The same mechanisms appear in the following case described by Dr. Rivers. A young man had always been troubled by a dread of inclosed spaces, so that he avoided underground railways, and suffered distress when traveling in a train going through a tunnel. His duties as a medical officer in the war brought him to a dug-out, where he was given a spade to dig himself out in case of emergency. This brought on an intense terror, with dreams of impending death. By way of a dream he was able to recall an incident of his fourth year, when he was badly frightened by a dog in going through a dark passage to the house of an old man to whom children brought discarded articles in exchange for pennies. Thus convinced that the source of his terror was a resurrection of this childish fright, he was able to overcome the dread of inclosed spaces. This type of avoidance under emotional stress (phobia) has its counterpart in the compulsions, common as neurotic symptoms, in which a set of mimetic actions must be gone through as a ritual to secure ease of mind, or to get to sleep. It may be a repeated washing (purification rite), or the rehearsal of some part of a scene connected with an inteusely (and to Freud a sexual) emotional incident, which has undergone suppression; *i.e.*, it is buried but buried alive, continuing as a source of (neurotic) unrest. A girl jilted by a cobbler in her deranged mental agitation constantly goes through the movements of sewing shoes.

In elaborating the genesis of neuroses and interpreting their symptoms, further concepts are reached. The most familiar is the complex which owes its vogue largely

to the contributions of Jung and Alfred Adler. Jung developed the association-test as a means of analysis. Calling out one word after another from a list of one hundred words carefully selected, the analyst asks the subject to reply as quickly as possible by the first word aroused in association with the stimulus-word, and measures the time to one-tenth second. Delayed reactions, remote or peculiar associations, hesitations and confusions, are looked upon as evidences of resistance or suppression, and thus indicate a complex. Special words are introduced to arouse suspected sources of emotional resistance. When some articles had been stolen in a hospital, the group of nurses coming under suspicion were subjected to such an association test, and the true culprit was detected through the delayed reactions to words connected with the theft.

Adler's chief contribution is in emphasizing the large part played by the ego-complexes in the handicaps and symptoms of the neuroses and in the interpretation of types of character and behavior. He regards any inferiority in function of an organ as a factor in developing a neurosis, as well as a cause of minor maladjustment. Inferiority and failure are unpleasant admissions against which conflict arises. Such an inferiority complex may lead to compensation by an unusual effort; it may lead to defense mechanisms to conceal its presence; it may invite recourse to phantasy or to other neurotic symptoms. There is also the superiority complex, which Freud recognizes mainly in the self-admiration Narcissus type with marked sex-features, possibly perversions. The ego-urges form the chief rivals to the sex-urge; the two reach their zenith together and in Freud's view the ego-urge is strongly sexualized.

Thus arises the concept of the libido, originally and literally expressive of sexual vigor, but expanding to include all vital urges as sources of energy. The career of the libido plays a dominant rôle in the Freudian drama. It is the fixation of this libido upon the parent of the opposite sex (Œdipus complex; Electra complex) or upon love objects, or emotionally disturbing episodes, that generates anxiety states, or compulsions, or abnormal phenomena generally. The varieties of neuroses, from temporary functional incapacity to serious insanities (delusions), occupy the subject matter of the Freudian doctrines, including the minute study of the mechanisms by which they come to expression.

Applications. The Freudian ideas have been broadly and variedly applied. The analytic type of diagnosis has been extended to the explanation of traits, behavior trends and character types among normal persons, types, however, in part allied to neurotic varieties. The chief distinction is that of the *extraverted* and the *introverted.* The former expend their energies (libido) upon outward activities, become absorbed in concrete pursuits and occupations. They proceed in a fairly matter-of-fact temper, are less troubled by inner hesitations, are more direct, simple, objective and represent the more common, more normal group. The latter are subjective, beset with hesitations and repressions, more subjective, imaginative, sensitive, difficult. To the carrying out of this distinction with further detailed divisions of subtypes, Jung has devoted a large volume. That a generically similar distinction is implied in James's delineation of the tough-minded and the tender-minded, is approached in such contrasts as realist and idealist, or, even more simply, in doer and dreamer, is obvious. Naturally types are not rigidly divided but present shades and grades; yet the Freudian analyses point to the major contours along which significant distinctions lie.

In illustration of the mechanisms, one may cite rationalization as a common and important one. The term indicates the tendency to assign logical reasons in defense of actions or attitudes which are at bottom motivated by feeling states of the Freudian order, such as jealousy, revenge, suppressed antipathies, inferiority states, compensation phantasies. When a man of some talent but essentially unstable chose for the subject of a lecture: "How I Achieved Success", he was betraying the

suppressed conviction that in reality he was a failure. Beliefs, even philosophical convictions, are colored by personal emotional attitudes and temperamental failings. Self-deception and hypocrisy may be rooted in protection of an ego-feeling, maintaining outwardly one personality, to conceal an unwelcome acknowledgment of the real self. From this approach the application to the field of morals is close at hand. It may be argued that unwise repression and too early and intense fixation of strong trends (of the libido) are dangerous and may blight or thwart the fuller natural development of traits. Perversions result when primitive trends find false outlets, — to Freud typically in the sexual sphere. Such attitudes and ideals as are expressed in asceticism or Puritanism suggest oversuppression; for which nature may exact toll in the form of neurotic symptoms, or maladjustments. The spinster's overconcern for animal pets is interpreted as a thwarting of the mothering impulses. The more desirable solution is formulated as sublimation, which is the diversion of energies rooted in strong urges toward outlets sanctioned by society and of benefit to the individual. The fine arts thus arise. The poet sublimates his phantasies, and no less the hero in action or fiction, both inspired by the love passion. In specific application anger becomes moral indignation; and mere curiosity (possibly of spying sex type) is not unrelated to scientific inquiry. How far religious emotion is similarly affected and the renunciation of the hearth leads to the seclusion of the cloister, is, like most such applications, a matter of delicate judgment. The same holds in the explanation of criminal or anti-social trends and the large and difficult problems of maladjustment distinctive of modern society, of the psychopathic members particularly. It is the purpose of the Freudian system to aid in their interpretation.

The application to the products of racial psychology, to the analysis of myth, of custom (of taboos particularly as embodiments of suppression), to the establishment of tribal cults by subconscious following of impulses and feelings rather than by conscious reflection, to fairy tales, to symbolisms, suggests another far-reaching expansion of Freudian ideas, which is further continued in the interpretation of types of dramatic heroes real or conventional. While suggestive, such applications are highly speculative and proceed by methods lacking verification. A further problem relates to the manner and measure of organization of the subconscious procedures, possibly of a subconscious self. Whether such a surging upward of impressions and operations without support of conscious direction may account for so-called inspiration, for calculating and chess-playing prodigies, and again for trance and divided personalities, is a difficult but interesting question.

Critical. It cannot be said that a generally acceptable estimate of the value and bearing of the Freudian doctrines has been reached; or that the future of the position can be predicted. The value of the psychoanalytic treatment has been questioned. Does it act by way of suggestion, or is it a true alleviating principle? To what cases does it apply? Equally opposed are positions as to the validity of the underlying concepts, or their interpretation. Extreme advocates and extreme opponents are readily found. A growing group (especially medical writers in England since the war, impressed by the insight conferred upon shell-shock cases) reject extreme and speculative factors (parent-fixations, sexual overemphasis, arbitrary symbolisms) and direct the principles to a useful and moderate interpretation of the fundamental mainsprings of attitude and behavior. Once it is seen that the more doubtful positions are not essential to the integrity of the Freudian approach; and, furthermore, that the developments, corrections and expansion of the Freudian ideas may be fitted to the progressive views of psychologists, the incorporation of the valid portions of the system seems assured. That it has served as one of the most important stimulations to psychological thinking and has profoundly affected modern attitudes toward significant problems in many fields cannot be questioned.

THE CLOUDS OF THE SUN

Revelations Arrived at by Direct Observation and by an Analysis of Sunlight

STORM-CLOUDS THAT RAIN MOLTEN METALS

THE blazing disc we see when we look at the sun is not the body of the sun, but only the outer surface of the clouds which completely surround and cover it. This mantle of incandescent clouds, of unknown thickness, is called the "photosphere", or light-sphere. Within it is the central core, containing by far the greatest proportion of the total mass of the sun, though we cannot by any possibility see it. Outside the photosphere, and enveloping it completely, and partly penetrating it is a layer of relatively cooler gases and vapors, called the reversing layer, beyond which is a second mantle, of rosy color, called the "chromosphere", or color-sphere. This consists not of clouds, but of gases, especially of hydrogen, and is invisible except at times of eclipse or to an observer with the spectroscope. Outside the chromosphere, again, is a vast, mysterious, ever-varying system of radial streamers of light, extending outward to prodigious distances. This halo, hitherto seen only at eclipse, is known as the "corona", or crown. Reckoning from within outward, therefore, we have the nucleus, the photosphere, the reversing layer, the chromosphere and the corona; and we shall consider them in that order.

The central nucleus, as we have seen in earlier chapters, is a mass of intensely heated gases under enormous pressure. The temperature and the pressure alike are greater than any we can well imagine, and together are supposed to produce a condition for which laboratory experiments can show no analogy. The temperature is so high that even under the pressures to which they are there subjected these gases do not liquefy; and, enormous as the temperature is at the surface of the sun's globe, it must increase to an incomparably higher degree towards the center. The pressure is such that the mixed gases become denser than water, attaining a density considerably greater than 1.42, which is the mean density of the sun; and inasmuch as the viscosity, or adhesive power, of gases is known to increase in proportion to the temperature, it is believed that the gaseous material of the sun's nucleus has a consistency somewhat like that of putty. Yet, with all this density and clinging stickiness, the sun's core never ceases to be gaseous. Though this state of things is barely imaginable, it is not on that account at all impossible. Yet it must be borne in mind that there neither has been, nor, so far as we know, is ever likely to be, any direct observation of the nucleus of the sun. All conclusions with regard to it are merely inferential.

The photosphere, or mantle of incandescent material forming the visible surface of the sun, is thought by many to consist of actual clouds with a considerable likeness to those of the earth. According to this view, just as our clouds are formed by the condensation of vapor, by cooling, into minute droplets which float in the atmosphere, so the sun-clouds are formed by the condensation of metallic vapors, by cooling, into minute droplets and crystals, that float in a similar manner in the gaseous solar atmosphere.

How the sun clouds drop showers of molten metal into the blazing abysses

In the same way as our clouds do not in general extend over us in an unbroken roof, but are separated from one another and make a kind of pattern in the sky, so it is with the sun-clouds. They, too, give a distinct characteristic texture or pattern to the visible surface of the sun. As our clouds drift with the winds, are whirled in cyclones, and are drawn out into long streamers, so are the sun-clouds. And it is not unreasonable to believe that just as our clouds fall in rain, so the clouds of the sun drop showers and cataracts of molten metal into the blazing abysses below them.

The only really serious difficulty against this view is the very high temperature of the photosphere which would exclude the presence of any solid or liquid except perhaps in the highest and relatively cooler layers, and in the sun-spots.

How telescopes and telescopic photography are used in studying the sun

The sun's surface is studied by means of telescopes constructed in such a way as to reduce the light to a degree comfortable for the eye, and by photography in conjunction with telescopes. When seen by either means, the photosphere presents a remarkably granular appearance. Innumerable bright, irregular grains or flecks are closely strewn upon a less brilliant background, and are irregularly grouped in clusters and curved lines. The general impression has been compared to that given by snowflakes scattered on a gray cloth. Under the highest telescopic power and in exceptionally clear states of the earth's atmosphere, these grains or flecks have been seen to consist of yet smaller granules closely grouped together. These grains and granules have diameters, roughly speaking, of 1000 and 100 miles respectively, and are probably the outer ends of vertical columns of clouds or ascending currents of highly incandescent vapors; for where the solar atmosphere is much perturbed, as in the neighborhood of sun-spots, the grains are drawn out into long, irregular, parallel streaks and filaments.

Some of the changes which photography registers in the sun

Even in a perfect photograph this granulation is sharply defined only over limited areas, separated by an irregular network of patches in which the solar surface appears misty, confused and non-granulated, very much as if it had been out of focus, or as if the photographic plate had in some other way been blurred by a network of streaks. This "photospheric reticulation" (*i.e.*, network of the photosphere) changes in such a way that although two photographs taken within a few moments of one another show the same reticulation, the form of the network is found to have changed if an hour or more has elapsed between the first photograph and the second. This local indistinctness, obliterating the granular structure, is probably due to violent motions of the sun's atmosphere, preventing any clear vision through the regions in which they may happen to occur; and the changes of reticulation will in that case be due to the motion of atmospheric storms across the surface of the sun. "The simple fact is," according to the late Professor C. A. Young, "that we are looking down upon the granules and other features of the sun's surface, not through an atmosphere shallow, cool and quiet like the earth's, but through an envelope of matter, partly gaseous and partly, perhaps, pulverulent or smoke-like, many thousand miles in depth, always profoundly and violently agitated."

To this smoky character of the photospheric atmosphere is ascribed the comparative darkness of the background against which the incandescent clouds are seen. The metals rising from the interior in the form of vapor, in mighty ascending currents, are first condensed into incandescent droplets or crystals, and so give rise to the luminous clouds; and then, becoming further cooled as they radiate their heat into space, lose their incandescence and form a smoke or fog which sinks downward between the clouds, until it reaches a level at which the temperature is sufficient to convert it again into vapors of the metals.

Why the light of the sun appears to us to be more brilliant in the middle

The same smoke, pervading the atmosphere around and above the brilliant clouds, accounts for the remarkable absorption of light at the edge of the sun's disc, or, as it is usually called, at the "limb" of the sun. It is obvious that, since the shining surface of the sun is a sphere, the light which comes to us from near the edge of the apparent disc must pass through a greater thickness of the overlying solar atmosphere than light which comes to us from the center of the disc. From the diminution of the sun's brilliancy towards its edge, which is very evident when the sun is viewed through a smoked glass or through an evening haze, it is reasonable to infer that the atmosphere of the sun intercepts a considerable proportion of its light.

By means of the spectroscope, it is possible to determine the chemical elements present in the outer layers of the solar atmosphere.

A description of this instrument in its various forms, and of the results gained by it, appears in another part of this work, and need not be repeated here. It is enough if we understand that white light consists of a blend of lights of all colors, from red, through orange, yellow, green and blue, to violet, with every intermediate shade of color; that every particular shade of color is given by light-waves of a definite length, the waves of red light being the longest and those of violet light the shortest; and that there is an indefinitely extended series of wave-lengths longer than those of red light, and similarly and indefinitely extended series of wave-lengths shorter than those of violet light. The range of color from red to violet marks, not the limit of the longest and shortest light-waves, but the limit, in each direction, of human vision.

Now, if, by means of the spectroscope, a ray of white light is passed through a narrow vertical slit, in order to give it the definite shape of a thin ribbon stretched horizontally with its edges vertical, and if it then passes through a prism of glass, the innumerable colored lights constituting the white light are separated out by the prism, according to their wave-lengths. So the light which entered the prism as a single white ribbon leaves it as a series of innumerable divergent colored ribbons. But if the ribbon of light entering the prism, instead of being white and containing all wave-lengths, consists of light containing, let us say, only three or four definite wave-lengths, it will emerge from the prism as three or four definite divergent ribbons. In the spectroscope the ends of these ribbons of light come into view side by side as a row of vertical colored lines, or colored images of the slit, extending from deep red at the left hand to violet at the right. In the spectrum of white light these vertical colored lines, however narrow the slit is made, touch and overlap, forming a continuous spectrum. We may compare the spectrum to a fence of vertical laths. In a continuous spectrum the laths touch and overlap. In other spectra, however, there are laths, many or few, here and there; and as every part of the fence is accurately mapped, the spectrum produced by any special source of light can be definitely recognized.

The use of the different spectra in examining the sun

There are certain principles, of great importance, which reveal the *nature* of a distant source of light. Thus, a continuous spectrum, comparable to a fence in which all the laths are present, comes from an incandescent solid, or from an incandescent liquid, or from an incandescent gas under great pressure; that is to say, such bodies, whatever be their chemical composition, when heated so as to become self-luminous, give out light of all wave-lengths within the range of vision. A discontinuous spectrum, on the other hand, comparable to a fence from which many or most of the laths are absent, comes from an incandescent gas that is not under great pressure, or from a mixture of such gases. That is to say, any material in the gaseous condition and uncompressed, whether it be one of the bodies

we know on earth as a gas, or whether it be a metal heated to such a degree as to become a luminous vapor, gives out only certain lights of definite wave-lengths, and so produces a spectrum characteristic of that particular gas or vapor. This spectrum consists of bright lines and bright bands, at certain definite parts of the whole range of the spectrum.

How the story of the chemistry of the sun is read in its spectrum

But besides the continuous spectrum and the discontinuous spectrum of bright lines and bands, there is a third kind of spectrum, which for the study of the chemistry of the sun is the most important of the three. This is a discontinuous spectrum of dark lines, superimposed upon the continuous spectrum of all the colors. It depends upon the remarkable fact that any gas, interposed between an incandescent source of light and the spectroscope, absorbs exactly those kinds of light that would constitute its own bright-line spectrum if itself were to be incandescent. The intervening non-luminous gas throws dark lines upon the spectrum, exactly in the places where it would throw bright lines if itself were the source of light. Such a spectrum is said to be a "reversed spectrum".

In consequence of this principle, it is possible to identify the comparatively non-luminous gases and metallic vapors present in the atmosphere of the sun, around and above the photosphere. The underlying photosphere gives a continuous spectrum, but each of the intervening gases and metallic vapors in the solar atmosphere absorbs light of certain definite wave-lengths.

The solar spectrum, therefore, as we receive it, is a continuous spectrum crossed by a vast number of dark lines. These dark lines tell the story of the chemistry of the sun's atmosphere.

We have spoken of these intervening gases as *comparatively* non-luminous, because they are non-luminous only in comparison with the far greater brilliancy of the photosphere. They are actually luminous, though in a far lesser degree. This is beautifully seen in eclipses of the sun, when the solar atmosphere shows its own bright-line spectrum for one brief moment before the moon, which has already eclipsed the sun's disc, eclipses its atmosphere also. For that brief moment the sun's atmosphere is seen to act, not as a veil throwing a dark-line spectrum, but as a source of light throwing a bright-line spectrum. This momentary spectrum is called the "flash" spectrum, and was first observed by Young in the total eclipse of 1870.

By means of the dark-line spectrum it has been proved that the sun contains a large number of the elements familiar to us on earth. It is hardly worth while to lay much emphasis on the failure to discover any particular element in this way, as the list of those definitely determined is continually being enlarged. Yet the apparent absence from the photosphere of some of our commonest terrestrial elements, such as nitrogen, chlorine, sulphur, etc., is so remarkable as to need some explanation.

Does the fierce heat of the sun ionize the elements and change their spectra?

The matter has been much debated, and two theories are at present maintained to account for their omission. The first theory holds that the lines of certain elements in the sun are cloaked or entirely suppressed by the presence of the other elements. The second theory is based upon the fact that certain elements are known, under laboratory conditions, to give different spectra according as they are subjected to different treatment; and it is reasonably enough suggested that in the solar heat the spectra of some of our familiar elements may be so altered, particularly by the ionization of these elements, as to escape recognition. A third view, originated by Sir Norman Lockyer, but now almost universally discarded, is to the effect that these substances which the spectroscope fails to find in the solar atmosphere are not really elementary substances, but are there split up into their constituent elements, having separate spectra which are unknown to us.

Strange appearances on the sun's atmospheric covering or photosphere

We have seen that the visible surface of the sun has a granular appearance, indicating a complex structure of the photospheric shell. Nothing is known as to the lower limits of this shell, nor whether it is separated from the sun's nucleus by any definite surface. The upper or outer surface of the photosphere is, however, very definite, as may be seen from the sharply cut edge of the sun's disc.

Yet there are irregularities of two kinds on the surface of the photosphere, both of great interest. In some parts the luminous clouds, which generally lie in a more or less level plain, rise to form great mountains and ridges of incandescent cloud-stuff, appearing to the observer as patches and streaks greatly exceeding in brightness the surrounding regions. In other parts the brilliant surface of the photosphere may be seen to be torn apart, or deeply depressed in the smoky atmosphere, so as to produce patches that are quite dark as compared with the surrounding surface. The patches of brightness are known as faculæ — that is to say, "little torches"; the dark patches are known as sun-spots (see page 1787).

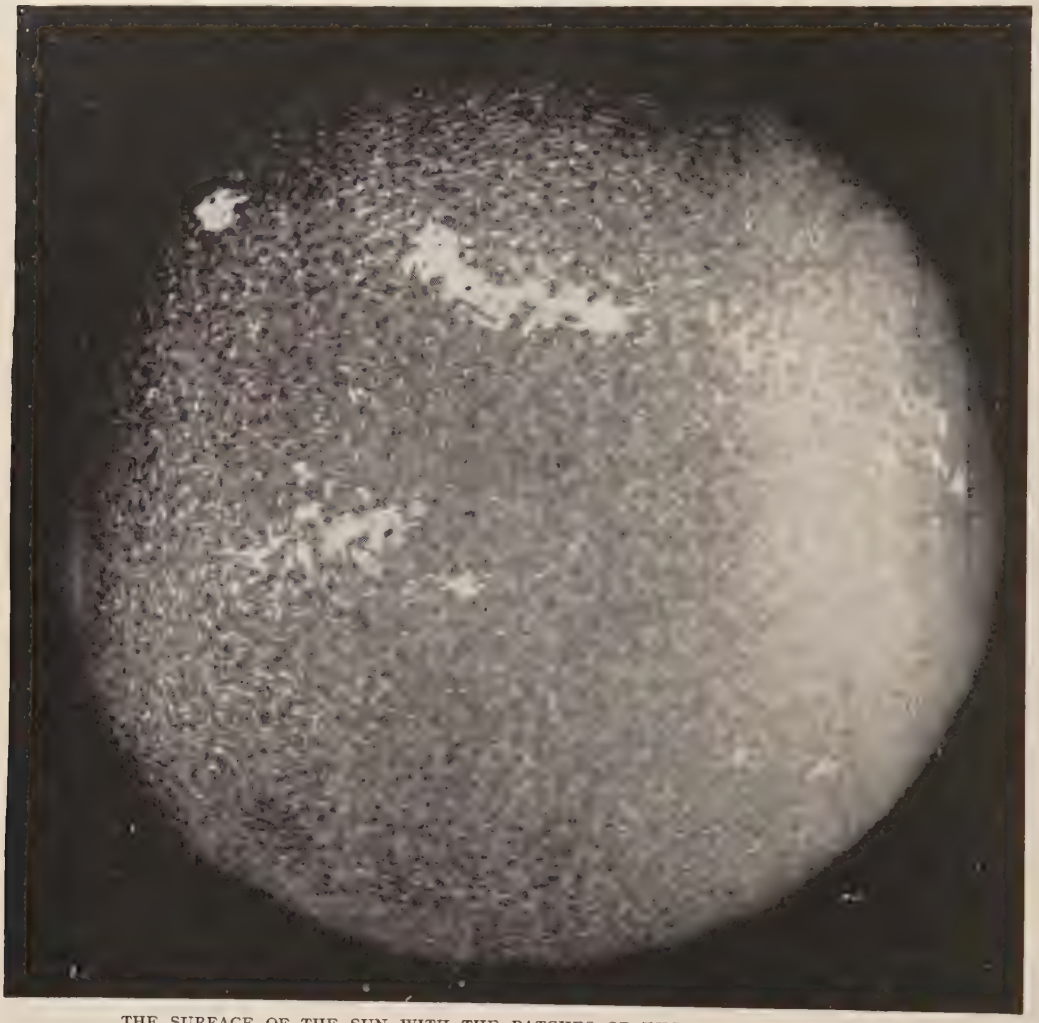
The flaring brightness of the sun's surface that makes other brightness dark

Spectroscopic methods have shown that the faculæ are formed in every part of the sun's surface, though they are far less numerous towards the poles than elsewhere, and are especially numerous in the vicinity of sun-spots. However, to an observer with a telescope, faculæ are visible in the regions of diminished illumination towards the edge of the disc, but are invisible in the more brilliant central regions of the image. The reason for this difference is found in the fact that though they appear only like little patches of extra brilliancy, the faculæ are vast elevations of the photospheric cloud surface, often many thousand miles in diameter, and rising to great heights in the solar atmosphere. This atmosphere, as we have seen, absorbs a considerable portion of the light from the photosphere, but does so to a very much greater degree towards the edge of the disc than towards its center, because light coming from the edge has to penetrate a much greater thickness of atmosphere than light coming from the center. Inasmuch as the incandescent faculæ rise far through the solar atmosphere, and may in some cases even extend above it, their light suffers little, or in extreme cases no, diminution from the atmospheric veil, and is consequently nearly or quite as bright towards the edge of the sun's disc as it is in the central area of the disc. Towards the edge of the disc, however, the general surface of the sun, forming the background against which they are seen, is far less brilliant, and the faculæ are consequently far more conspicuous than in the center of the disc, where, owing to the comparative thinness of the atmospheric veil, there is no great difference in brightness between the faculæ and their surroundings.

That the faculæ are eminences rising far above the general surface of the photosphere is proved by the sight of them sometimes in profile at the edge of the sun's disc, where they appear as minute and very brilliant projections of the outline. The spectroscopic evidence to the same effect is very striking, and has been made the means of showing the existence of faculæ in the central regions of the disc. It will be remembered that the gases of the solar atmosphere, though enormously hot according to all terrestrial standards, are relatively cool as compared with the photosphere which lies below them, and therefore act spectroscopically, not as themselves an incandescent source of light producing a bright-line spectrum, but as gases interposed between the source of light and the spectroscope, producing a reversed spectrum of dark lines. From certain patches of the sun's surface, however — namely, from the faculæ — these gases and metallic vapors, or some of them, give a bright-line instead of a dark-line spectrum, proving that in such places the hotter substances from below have been projected upwards through the comparatively cooler atmosphere.

"Suppose, for instance," says Sir Robert Ball, "a prominence consisting of a vast mass of glowing calcium vapor is projected to such an elevation in the sun's atmosphere that the brilliance which the incandescent vapor pours into the calcium lines more than compensates for the absorption due to the cooler calcium vapor outside, then we have what is called a reversal of those particular spectral lines. Sometimes the singular spectacle is presented which is known to spectroscopists as a double reversal; in this case the ordinary dark line is filled with a rather broad band of luminosity, and down the center of the bright band a fine dark line is found to be inserted. In this case we interpret the double reversal to be an indication of the presence of a volume of glowing gas overlaid by a not very copious atmosphere of the same gas in a cool state."

Photographs taken of the sun by means of the spectroheliograph, which admits light belonging only to one part of the spectrum, show faculæ all over the disc of the sun; and from a series of photographs of this kind it has been shown that in general the faculæ change their shape very slowly, and often remain unaltered from day to day. In the vicinity of sun-spots, however, they are subject to violent changes.



THE SURFACE OF THE SUN WITH THE PATCHES OF EXCEPTIONAL BRIGHTNESS
This spectroheliograph was taken at the Yerkes Observatory on April 27, 1903.

Sun-spots are in several respects the most striking features of the surface of the sun. They are sometimes so large as to be seen easily with the unassisted eye, and have therefore been known for many centuries, though until comparatively recently they were taken to be planets passing between the earth and the sun. It was not until the advent of the telescope early in the seventeenth century that their true nature as dark spots on the solar surface was clearly recognized. They have been much studied during the last fifty years, but astronomers are not yet fully agreed with regard to their nature and causes.

A typical sun-spot has the appearance of a more or less circular aperture in the incandescent photosphere. Its center is an apparently very dark area, like the mouth of a pit, called the "umbra"; and round this central black spot is a moderately dark border, called the "penumbra", consisting of irregular, wavy streamers of cloud grouped more or less radially. The umbra is not really dark, but is actually very brilliant; it appears dark only in contrast to the surrounding regions of the blazing photosphere. Its area is often pierced by a few small round spots much darker than itself, and these are supposed to represent pits penetrating to the deeper abysses of the sun. The penumbra apparently consists of incandescent clouds drifting into the umbra, and seems brighter at its inner edge, next the umbra, than at its outer rim, next the unbroken surface of the photosphere. The tips of the clouds of the penumbra break off and melt away in the umbra.

Are the sun-spots atmospheric whirlpools around holes in the sun's cloud-mantle?

Sun-spots are not by any means always circular, but assume a great variety of forms, some of them extremely irregular. The faculæ, or "little torches", described above, are numerous in their neighborhood, indicating, like the sun-spots themselves, violent perturbations of the solar atmosphere. Individual spots arise as minute specks, grow in size, change their shapes, often divide into two or more spots thus forming a group, and, after persisting for a few days, weeks or months, finally disappear. Most of them last about eight or ten weeks, but sun-spots have been known to remain for a year, and even for eighteen months.

Some spots are plainly depressions in the surface of the photosphere, but their appearance varies greatly and no general conclusion can be drawn from the conflicting testimony of different observers as to the surface level of sun-spot areas.

The size and distribution of sun-spots over the sun's surface

Sun-spots vary greatly in size, one of the largest on record having a diameter of 143,000 miles. This, however, is very exceptional, and one having a diameter of 20,000 miles is considered fairly large.

Sun-spots are not equally distributed over the surface of the sun, but occur chiefly in two zones, one in the northern hemisphere and the other in the southern hemisphere, at equal distances from the equator. The poles and the equator are nearly free from spots, and by far the greater number appear between the latitudes of 10 degrees and 35 degrees north and south. Sometimes the northern hemisphere, and at other times the southern, is more affected by spots than the other; for example, a period of forty years has been known to pass without any appearing on the northern hemisphere at all.

Sun-spots have movements of their own; thus, a small proportion of them rotate in one direction or in the other, and the two spots formed by the division of a single spot are sometimes seen to fly apart with great velocity. In general, however, the sun-spots move with the surface of the sun, and are consequently useful in determining the direction of the solar axis and the speed of the sun's rotation. By observations of the movements of sun-spots the remarkable fact was discovered that while a point on the sun's equator makes a complete revolution in little over twenty-four days, a point at 50 degrees north latitude takes over twenty-seven days for one revolution. That is to say, the sun, or at least the photosphere, does not rotate in one piece as a solid body would do,

but the equatorial regions rotate considerably faster than the regions about the poles. Various theories have been brought forward to account for this fact, but none of them has proved altogether satisfactory.

Some apparent influences of sun-spots on the atmospheric conditions of the earth

The frequency of sun-spots is greater in one year than in another; and it has been definitely ascertained that the times when there are fewest and the times when there are most alternate with considerable regularity and at fairly constant intervals. The average interval between one time of maximum activity and the next is rather over eleven years. In this period about six and a half years show declining activity and the following four and a half years show increasing activity. The periodic rise and fall of the frequency of sun-spots is unquestionably related to a periodic increase and decrease of disturbances in the magnetism of the earth, as shown, for instance, in particularly brilliant displays of the aurora borealis.

From this relationship it was for a long time supposed that sun-spots were of a magnetic character, but it was not until the application of the spectroscope to sun-spot investigation, especially by Hale in 1908, that direct evidence of the magnetic fields in sun-spots was secured and the polarity and strength of their fields were determined.

Thus the magnetic influence of sun-spots is thoroughly established but it is not so certain that a clear connection can be made out between the periods of sun-spot activity, on the one hand, and the condition of our weather, the value of our crops, and the state of our trade, on the other hand. A great deal of ingenuity has been devoted to showing a connection of that kind between solar changes and terrestrial affairs, and any positive knowledge, for instance, of the influence of sun-spots on crops, and indirectly on credit, would be highly valuable. Men of great authority have supported such a theory, but others, with not less authority, have hitherto rejected it.

The arguments for and against the whirlpool theory of sun-spots

The nature and causes of sun-spots are not yet fully understood. Many elaborate theories have attempted to account for their origin, but of these there remain only two which at present receive any considerable support. One, brought forward by the French astronomer, Hervé Faye, and later confirmed with some modifications by a large mass of spectroscopic work done at Mount Wilson and described by Charles G. Abbot in his notable work on "The Sun", regards a sun-spot as caused by a vast vortical movement in the sun's atmosphere, of the same kind as our whirlwinds and cyclones, only on a prodigiously larger scale. It is supposed that these vortical whirls create conical tunnels in the mass of the photosphere; this whirling motion is accompanied by an expansion and consequent cooling of the materials involved, so that the temperature falls perhaps as much as 2000° C. with a corresponding diminution of brilliancy.

Other suggested explanations in an unended and baffling controversy

The other theory, originated by Secchi, regards the sun-spots as formed by masses of metallic vapors which, after being thrown up by eruptions in the sun's surface, have become relatively cool in the upper regions of the atmosphere, and then, descending upon the surface of incandescent clouds, have formed the depressions in the luminous surface we know as sun-spots.

This theory was the one favored by Professor Young who wrote as follows: "It may be that the spots are depressions in the photospheric level, caused not directly by the pressure of the erupted materials from above, but by the *diminution of upward pressure* from below, in consequence of eruptions in the neighborhood, the spots thus being, so to speak, *sinks* in the photosphere." Possibly it is safest to suppose that no simple theory will ever account for these very complex phenomena.

THE WONDERS OF WATER

Where It Comes from, How It Was Made, and Why It Varies in Its Composition

TESTING THE DIFFERENT SEA WATERS

IT is an amazing thing that the hard, stony earth should be encircled by that curious collection of nimble gases known as the atmosphere. Almost more amazing is it that the world should carry its wonderful burden of that substance known as "water", and should carry it in three shapes — as vapor, as liquid and as solid. Practically, all other things about the surface of the earth are solid, but the atmosphere remains gaseous, and the water hesitates in an unstable condition of betwixt and between.

The temperature of the earth has fallen a good many thousand degrees since the crust of the earth was molten, and now a fall of a few degrees more would freeze the ocean. A further fall of a few degrees, and a sea of liquid air would cover the frozen ocean. A still further fall, and everything in the world would be solid. The difference between a world with balmy breezes and rolling seas, and a world with neither atmosphere nor ocean, is only the difference of a few degrees Fahrenheit. Fortunate it is that air and water are the last to solidify; that they were there to *be* last, for without them the world would be a shriveled, dry mummy, like the moon.

Water is a particularly surprising substance. It is a compound of two gases, hydrogen and oxygen, and it is a compound which does not form spontaneously. How, then, does it happen to occur in such large quantities? It is true that all the water on the world only wets the earth in proportion to its size as an apple is wet by a misty rain, but it required a vast amount of the gases to produce even so little moisture. How, then, is there so much of it? Where did it come from? When did it come? These are interesting, difficult, inevitable questions.

One thing is certain: that is, that when the crust of the earth was hotter, any water there might be then must have existed in the form of vapor. The great basins of liquid water are the ocean beds, but until the crust of the earth had cooled for thousands of years the ocean beds could have held water no better than a red-hot frying-pan. Were, then, all the oceans once up in the air? Did the sea-water and the polar ice, and all other water, originally form a huge atmosphere of vapor? No; we cannot believe that. The sea as vapor would have hundreds of times its present volume, would have formed an atmosphere thousands of miles high, and the earth could not have retained such a voluminous and volatile atmosphere. Even if the earth could by any possibility have held such a vast atmosphere of water-vapor, we should still have to explain where this vapor came from, and how the compound was formed.

We surmount the difficulties and obtain a plausible answer to the problem only by assuming, as we assumed in the case of the atmospheric gases proper, that the water-vapor was formed not all at once, but by degrees, so that at no time did the earth's atmosphere contain more water-vapor than the earth's gravitative power could grip. Good! But *how* was the water-vapor gradually formed? How was this marvelous compound of hydrogen and oxygen produced?

There are two or three possible sources of water-vapor. In the laboratory water may be made by passing an electric spark through a mixture of hydrogen and oxygen. Now, it is probable that, in the early volcanic days of the earth's existence, hydrogen was belched forth by volcanoes in great quantities; and it is probable that in the same early days lightning-storms were more violent and more frequent than now, and so it is quite likely that the lightning, as it flashed through the atmosphere, combined oxygen and hydrogen into water. So much water, then, would be formed in the atmosphere by lightning, and would gradually condense as opportunity offered. That would be a worthy birth of this wonderful substance — to the flash of lightning and the roar of thunder, from the flames of volcanoes.

But a more important factory of water would be the bowels of the earth, and from this factory water would be sent to the surface ready-made. Meteorites contain, among other gases, hydrogen; and there can be no doubt that there was hydrogen in solution in the molten crust of the earth, and that a considerable quantity of hydrogen must have been stored subterraneously.

How in all likelihood the ancient volcanoes threw up the oceans

Under the right conditions of temperature and pressure the hydrogen would take oxygen from the ferric oxide of the earth's crust, or join any free oxygen it could find, and form water, and this water would reach the surface of the earth by means of hot springs, and geysers, and volcanoes. Probably volcanic steam is the chief source of water, and possibly alone suffices to account for all the water in the world. What a pretty paradox is this — water, the extinguisher of fire, made by fiery volcanoes!

The amount of steam discharged by a volcano is surprisingly large; from one subsidiary cone of Mt. Etna, according to careful estimation, in 100 days, 460,000,000 gallons of water were blown out as steam. In the early days of the world volcanoes were probably much more numerous, and volcanic action was probably much more vigorous. It is noticeable that all the great seas are ringed by volcanoes; and how many volcanoes may have formerly been spouting and snorting in the bed of ocean, who can say? Certainly the volcanic islands in the Pacific suggest violent volcanic action.

The story told in corroboration by volcanic dust flooring the ocean beds

Suggestive, too, of volcanic action is the volcanic dust found everywhere in the abysmal depths of the sea. It is true that this dust is usually supposed to have sunk through the water; but why, then, is it found only or mainly in the deep sea? It is quite as likely that it is the product of the same submarine volcanoes whose steam condensed as ocean water. Altogether it is not difficult to believe that, in one way or another, water is of volcanic parentage.

Having now found a source of the water of the earth, let us look at some of its properties. A most paradoxical substance is water. It is a compound of oxygen, a gas which supports combustion, and of hydrogen, a gas which burns, and yet it will not support combustion, and will not burn. Again, both oxygen and hydrogen are most difficult to liquefy and solidify, and yet at ordinary temperatures water changes from liquid to solid, from solid to liquid, with great facility. As vapor we find it constantly in the air; as snow and ice we find it wherever the temperature falls to 32° F. or below; and as liquid we find it, at some time or other, in almost every part of the world. Whether as gas, liquid or solid, it plays a most important rôle in the economy of nature.

One of the most unique characters of water is its capacity for heat. It has greater thermal capacity than any of the other common known substances, the thermal capacity of a substance being the number of heat units required to raise the temperature of unit weight of the substance one degree. On the same fire, under the same conditions, an ounce of mercury will grow as hot in half a minute as an ounce of water will grow in an hour. As a consequence of its heat capacity, hot water takes a long time to grow cold; and this and some other related properties of water have an important bearing on the question of climate.

Wherever land is surrounded by sea, or near the sea, the climate tends to be more equable than inland. Not only does the vapor the sea gives to the air act as a parasol by day, shielding the earth from the hot sun, and as a blanket at night, returning to the earth the heat that would otherwise radiate away, but the thermal capacity of water which we have mentioned has an even more marked effect in preserving an equable temperature. For since the sea requires much more heat to warm it than the land, it is like a cool wet cloth laid over the land sweltering with heat; and eighty cubic feet of air. When we come to talk of climate we will return to this topic.

It requires a great deal of heat to raise the temperature of water from 32 degrees F. (freezing-point) to 212 degrees F. (boiling-point), but in order to convert it into vapor a great excess of heat is required over and above the heat needed to make it boil. To raise the temperature of one pound of water from 32 degrees F. to 212 degrees F. requires 180 times as much heat as is required to raise its temperature one degree (*i.e.*, 180 so-called "heat-units" are required); but to convert the water at 212 degrees F. into

CRATER ON A VOLCANIC ISLAND THAT APPEARED NEAR TRINIDAD IN NOVEMBER, 1911

again, since it stores up great amounts of heat, it gives this to the land if the land be cooler than the sea. A pound weight of water requires as much heat as four pounds of air to raise its temperature one degree; and thus one pound of water can heat four pounds of air one degree at an expense of only one degree of its temperature. Also, air is seven hundred and seventy times as light as water, and hence one cubic foot of water, by surrendering sufficient heat to lower its temperature one degree, can raise through one degree the temperature of no less than three thousand

steam at 212 degrees F. requires no less than 967 heat-units, or more than five times as much as is required to heat the water to boiling-point from freezing-point. All this heat applied to the water to change it to steam does not raise the temperature of the steam, and it is therefore called "latent" heat. The latent heat in the steam becomes manifest again when the steam is condensed; and one pound of steam passed into five pounds of water at 32 degrees F. will, as it condenses, give off enough latent heat to raise the whole five pounds of water to 212 degrees F.

Suppose, now, heat is applied to ice, what happens? We find that if the ice is at zero F. each heat-unit will raise it 2 degrees, so that 16 heat-units will raise it to 32 degrees F. Ice is therefore twice as easily heated as water. But to convert the one pound of ice at 32 degrees F. into water at the same temperature no less than 144 additional heat-units are required. Here, again, the heat does not change temperature, but is *latent;* and here, again, the latent heat will become manifest if the water again freezes. This alternate absorption and release of heat by water as it changes its state is one of its most characteristic features, and fits it for the part it plays in transmitting and regulating natural energy.

THE SMOKING AND STEAMING ISLAND OF BOGOSLOV IN THE BEHRING SEA

A very remarkable anomaly of water is that its volume at 32 degrees F. is 8 per cent less than the volume of the same weight of ice. Thus water in freezing contracts; and if we examine the behavior of water as it cools down towards freezing-point we find that down to 39 degrees F. it contracts as it cools, just like ordinary liquids, but that below 39 degrees F. it strikes out a line of its own and begins to *expand* as it cools. The expansion at freezing, therefore, is merely a continuation of the expansion that began at 39 degrees F. In consistency, of course, when ice melts it contracts, and if the ice-water be heated it continues to contract up to 39 degrees F. It is not the thaw, accordingly, that bursts the water-pipes; the pipes may burst as the water cools, at any point below 39 degrees F. but if they have stood the expansion of freezing they are not likely to burst with the contraction of cold. Above 39 degrees F. water expands with heat and contracts with cold, just like ordinary orthodox substances.

This expansion of water as it nears freezing-point, and at freezing-point, is of great climatic importance. If water, like most substances, continued to contract as it cooled, then the cooler, denser water would continually sink to the bottom, and ice would form on the bottom and not on the top of water. That might seem very good for a while; we might miss our skating, but it would leave the St. Lawrence and the Baltic open to ships all the year round, and it would produce a milder climate round coasts hitherto icebound. But it would seem good only for a while. The ice formed at the bottom of the sea and lakes and rivers would not melt. Since water is a very bad conductor of heat, the sun would fail to reach it through the overlying water, and the surface water warmed by the sun would decline to sink and thaw it. It would remain all through the summer and autumn, and next winter a fresh layer of ice would be formed on top of it. This fresh layer, again, would persist through the succeeding summer and autumn, and would be covered by still another layer next winter.

In time, at this rate, all the seas and lakes and rivers within the reach of frost would become solid ice, and all fishes and water-animals would be slain. And now the climate, at first rendered milder, would be rendered much more severe. It would be a case of slush in summer and ice in winter; and the continents of Europe and North America would become icefields populated chiefly by famine-stricken polar bears, and the centers of civilization would shift to the Amazon and the Nile.

Almost every known substance is to some extent soluble in water, and all natural water has solids in solution. In salt water the taste of the salts in solution gives evidence of their presence, but even fresh, tasteless water has a certain amount of solid substance in solution. The chief mineral substance dissolved in fresh water is carbonate

LIMESTONE STALACTITES

STALAGMITES AND STALACTITES

of lime. All water contains a certain small amount of carbon dioxide in solution, absorbed from the air; and water, again, containing carbon dioxide in solution is capable of dissolving carbonate of lime; and since carbonate of lime is almost everywhere present, so all water contains carbonate of lime in solution. Water containing much lime in solution, whether carbonate of lime or sulphate of lime, is known as *hard* water, and in such water some of the lime in solution is liable to be precipitated. So-called petrifying springs are produced in this way. The water issues with a large amount of lime in solution, and when the water evaporates the lime remains behind and forms an incrustation on any objects which are in it.

In this way, too, are formed the remarkable bodies known as stalactites and stalagmites. Water laden with lime drips from limestone rock through the roof of a cavern, and, as it evaporates, leaves a little lime behind. This deposit gradually increases until formations of lime, shaped like icicles, hang from the roof. These are known as stalactites. Again, where the drops fall on the floor of the cavern, they deposit a little carbonate of lime, and to this deposit, drop by drop, a little more lime is constantly added, until in time little conical rods of carbonate of lime stand up from the floor. These are known as stalagmites. Sometimes stalactites and stalagmites join and form pillars.

River-water holds in solution from two to fifty grains of saline matter per gallon — on an average, say, about twelve grains.

The percentage composition is as follows:

Calcium carbonate	42.90	Carbonates 57.70
Magnesium carbonate	14.80	
Silica	9.90	
Calcium sulphate	4.50	Sulphates 11.40
Sodium sulphate	4.20	
Potassium sulphate	2.70	
Sodium nitrate	3.50	
Sodium chloride	2.20	
Iron oxide and alumina	3.60	
Other salts	1.30	
Organic substances	10.40	
Total	100.00	

Sea-water, as is well known, and as its taste indicates, is much richer in salts than fresh water. A gallon of sea-water contains about 2450 grains of saline matter. Its chief saline constituent is not carbonate of lime, as in the case of fresh water, but sodium chloride or common salt — the salt we use at table. Out of the 2450 grains of saline matter contained in a gallon of sea-water, there are over 2000 of common salt.

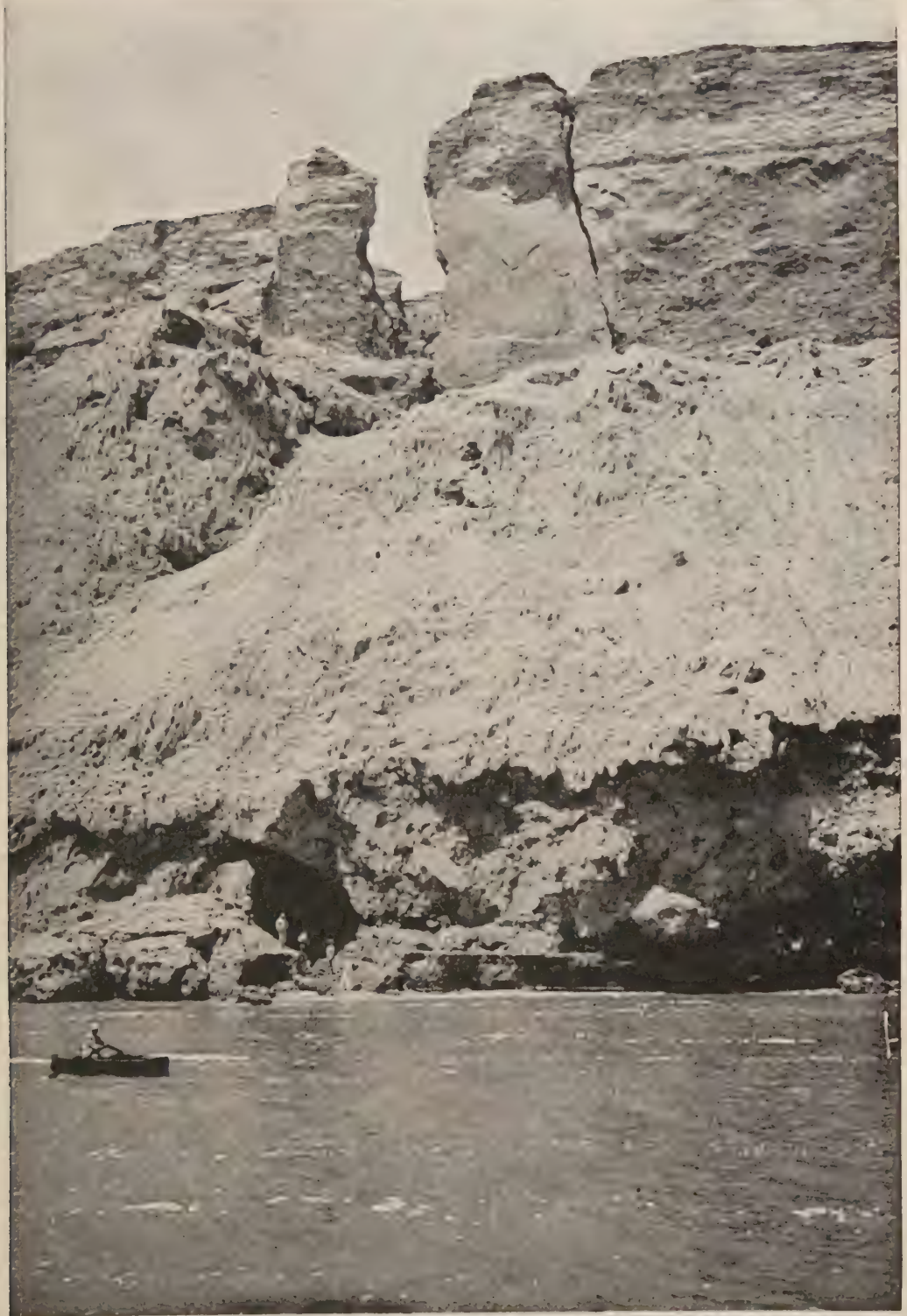
The constituents in parts per hundred are:

Sodium chloride	77.70	
Magnesium chloride	10.80	
Magnesium sulphate	4.70	Sulphates 10.80
Calcium sulphate	3.60	
Potassium sulphate	2.50	
Calcium and magnesium carbonate	0.30	
Magnesium bromide	0.20	
Other salts	0.20	
Total	100.00	

The solids, however, in solution vary in sea-water with the natural history of the water. The following interesting table, showing the salt contents of various seas, has been compiled by Bonney.

	English Channel	Mediterranean Sea	Black Sea	Caspian Sea (Baku)	Great Salt Lake (Utah)	Dead Sea
Chloride of sodium	2.7059	2.9424	1.4019	8.5267	11.8628	3.6372
Chloride of potassium	.0765	.0505	.0189	(trace)	.0862	.8379
Chloride of magnesium	.3666	.3219	.1304	.3039	1.4908	15.9774
Chloride of calcium						4.7197
Sulphate of magnesium	.2295	.2477	.1470	3.2493		
Sulphate of calcium	.1406	.1357	.0104	1.0742	.0858	.0889
Sulphate of sodium					.9321	
Sulphate of potassium					.5363	
Carbonate of calcium	.0033	.0114	.0364	.0554		
Carbonate of magnesium			.0208			
Bromide of magnesium	.0029	.0556	.0005			.8157
Water	96.4747	96.2348	98.2337	86.7905	85.0060	73.9232
	100	100	100	100	100	100

THE SALTY DEPTHS OF AN ANCIENT SEA-BED



A VIEW OF JEBEL USDUM, A MOUNTAIN OF ROCK SALT, WHICH EXTENDS FOR SIX MILES AT THE SOUTH END OF THE DEAD SEA, AND IS THE DEPOSIT OF AN ANCIENT OCEAN

It will be noticed that the salts in solution in the English Channel are not quite the same as the salts in solution in the Mediterranean, and samples collected by the *Challenger* showed variations between 3.301 and 3.737 in the percentage of salt in different parts of the sea. Besides these substances there are many other elements in solution in sea-water, such as iodine, fluorine, phosphorus, silicon, barium, lead, iron, copper, silver, cæsium and rubidium. Even a trace of gold is found, and more than one scheme has been proposed to recover it.

Since the salts in sea-water are derived from the land, it may seem strange that there is only a small quantity of silica and of carbonates; but the reason of this deficiency is that many marine animals and plants subtract the silica and carbonates from the sea-water in order to make themselves skeletons or shells. A single oyster requires all the lime in 27,000 to 76,000 times its weight of sea-water to make its shell. Spring-water contains more than ten times as much silica as sea-water; but at once the little unicellular plants called diatoms begin to use it to make their shell-like skeleton, and the store is quickly diminished.

As a rule, the water on the surface of the sea is saltier than the water in the depths, and the sea in regions where there is a large rainfall may have its salinity much reduced. The amount of ordinary salt (sodium chloride) and mineral matter in the sea seems inconsiderable when we state it as 3.3 to 3.7 per cent, but the following figures help one to realize how vast the amount really is: In every cubic mile of sea-water there are more than 117,000,000 tons of ordinary salt. If all the mineral matter in the sea were extracted and spread upon the dry land, it would form a layer more than 400 feet thick. If we could use the same mineral matter to extend the margin of the present continental areas out into the shallower seas, we could add about 20,000,000 square miles to the land surface of the globe; while if we were to heap up all the mineral matter on India, the Himalayas would be buried deep underneath. The common salt in the sea would itself form a continent having a bulk fourteen times that of the present European land above sea-level.

The result of all this mineral matter dissolved in the sea is to alter the thermal properties of sea-water as compared with the thermal properties of fresh water, as we have already described. The capacity for heat of sea-water is rather less, so that it is more easily warmed, and it conducts heat better. This very greatly increases the dynamical force of the sea. Sea-water is also more difficult to freeze than fresh: its freezing-point being about 28° F.

Most of the substances in solution in the sea have been added to it by the agency of streams and rivers; it is part of the débris of ancient continents. It has been added year after year, and century after century, and attempts have been made to estimate the age of the sea by calculating the time required to accumulate its salt.

Its solvent power enables sea-water to act in a certain sense as a vital fluid. In the higher animals the blood functions in a fourfold way. It absorbs and distributes oxygen to the tissues; it takes up from the alimentary canal digested foods and transports them in solution to all parts of the body; it carries off waste products from the active cells; and lastly it equalizes in its circulation the body heat. In some low but showy forms of sea life, the polyps, for example, both soft and hard, fixed like sea-anemones and corals, and also in free swimmers, the whole body surface takes in oxygen dissolved in the sea-water and gives off carbon dioxide. In these animals, cœlenterates, the pharyngeal opening and digestive cavity allow free circulation of the sea-water, which takes up the digested food and carries it to the different tissues. The soluble waste products are swept away by this blood-substitute.

Water contains not only solids in solution but also gases. Whatever gases happen to be in contact with it enter into solution, the amount depending on the solubility of the gas, on its pressure, and on the temperature of the water. The greater the pressure, the greater the volume absorbed; the higher the temperature of the water, the less the volume absorbed. If gas is absorbed under a certain pressure, it will bubble out again when the pressure is reduced, as in "soda-water".

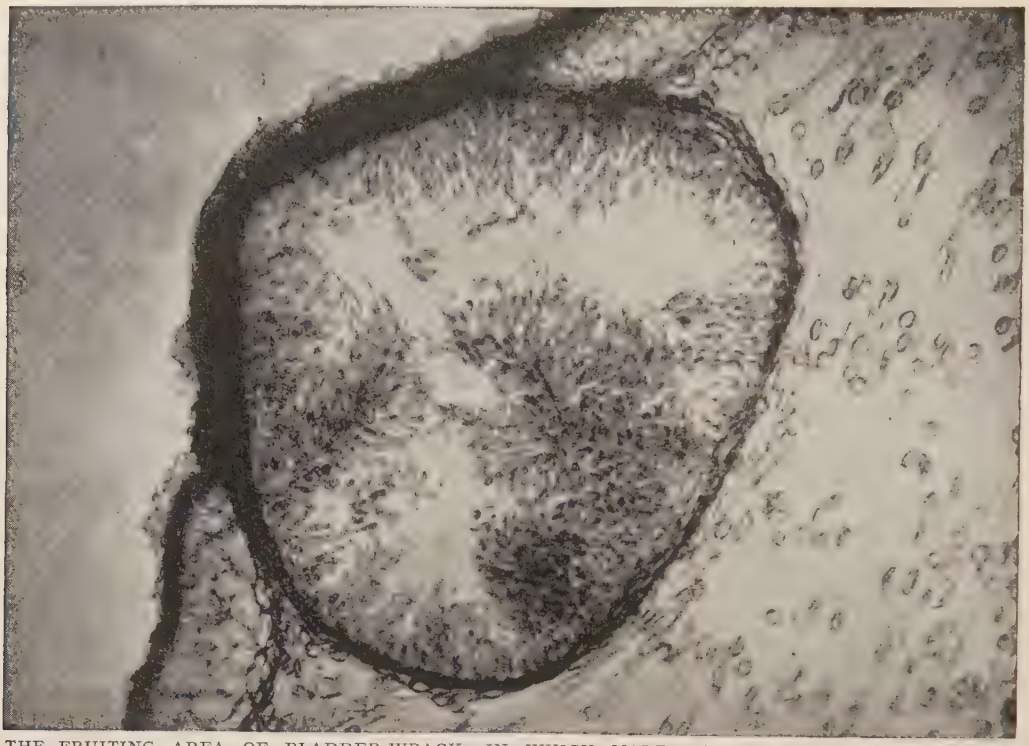
Natural waters are naturally in contact with the gases of the atmosphere, and therefore always have these gases in solution. At a temperature of 32° F. and at ordinary atmospheric pressure, 100 volumes of water will dissolve 2 volumes of nitrogen, 4 volumes of oxygen and 108 volumes of carbon dioxide, provided these gases are equally represented in the atmosphere, but since there is four times as much nitrogen as oxygen and only an infinitesimal amount of carbon dioxide, water contains in solution twice as much nitrogen as oxygen, and a very small quantity of carbon dioxide. The proportion of nitrogen in the water remains the same, however deep we go, but the proportion of oxygen diminishes, since oxygen is consumed in the processes of respiration by marine organisms.

All bodies of water give and take atmospheric gases, as the pressure of these gases and as the temperature of the water rise and fall; and in the case of the sea this give and take performs a very useful office in maintaining the equilibrium of the carbon dioxide in the atmosphere.

Though carbon dioxide occurs in only small quantities in the air, it plays quite an important part in the regulation of the temperature of the earth, and in the due performance of the respiratory functions of animals and of the digestive functions of plants. A little deficiency or excess would seriously affect all these; and it is produced in such large quantities by animals and volcanoes and coal-fires, and is consumed in such large quantities by plants and rocks, that considerable variation in its total volume might very well take place.

CŒLENTERATES EXEMPLIFIED BY SEA-ANEMONES, WHICH LACK ALIMENTARY CANALS DISTINCT FROM THE GENERAL CAVITY OF THEIR BODIES

Such variations are, however, automatically checked by the sea; for as the pressure of the carbon dioxide in the air rises, more enters into solution in the sea; and as it falls, some of it in solution in the sea returns to the air. How effective this regulation is the following will show: at present there are 3 volumes of carbon dioxide in 10,000 of air. In order to increase the proportion to 4 in 10,000 it would be necessary to more than double the amount originally present, for the sea would absorb much the greater part added.



THE FRUITING AREA OF BLADDER-WRACK, IN WHICH MALE GERM-CELLS ARE DEVELOPED

CONCEPTACLE OF BLADDER-WRACK, IN WHICH FEMALE GERM-CELLS ARE DEVELOPED

In the upper of these highly magnified photographs the spermatozoids can be seen in their receptacle, and in the lower are seen the large, dark-colored oogonia in which are produced the eggs which are fertilized by the spermatozoids. Photos by Mr. J. J. Ward

STUDIES IN HEREDITY

How Darwin and Galton Made a New Scientific Orthodoxy Which Has Already Been Superseded

THE FAILURE OF RESEARCH BY ARITHMETIC

IF we recall our study of reproduction, we shall realize that heredity offers no problem in the simplest possible instances. The bacillus or the amœba divides into two, and as each is half the parent, its resemblance to the parent is in the nature of the case. As regards the amœba, which has a nucleus, we saw that the contents of the nucleus are simply subdivided between the "offspring", to use a word which is evidently not yet applicable to the process of reproduction in such humble forms of life. In the case of the yeast plant we can speak of "offspring", for the young cell does spring off, so to speak, from the parent; but it is palpably part of the parent, and again the resemblance between the generations offers no problem to the student of heredity. Further, in such cases as these, which are drawn both from the animal and from the vegetable kingdoms of the living world, the new individuals are born adult. They have no youth, no immaturity, no period of development. So much the less is there any problem to study. We do not have to compare mature parents with immature offspring; we do not have to ask how the development of offspring, from immaturity up to a condition in which they resemble their parents, is made dependent upon the composition of "germ-cells" in which no trace of the future organs and limbs and features can be observed by the most powerful microscope.

Nevertheless, let us duly note these cases, and their simplicity; for the great initial discovery, upon which modern genetics is based, was the tracing of the hereditary process, in even the very highest forms of life, to just this same simple, continuous cell division as the amœba illustrates. That, in a word, is what the theory of the germ-plasm and the "continuity of the germ-plasm" means; and when we talk of germ-cells and study their origin from cells in the germinal tissue, though they be the germ-cells of an oak or of human beings, we are studying a series of processes of cell division which set free from the parent individual cells destined to carry forward the life of the race though all this is hidden from our eyes by the extraordinary development of the individual body from and around these germ-cells. And thus, if the resemblance between daughter amœba and the parent amœba is really no problem — for they are the mother, subdivided — so also the resemblance between successive generations of other species is seen to be inevitable, for the body of the parent is sprung from a "continuous germ-plasm", of which a further portion, reserved for the purpose years later, gives rise to the body of the offspring. Naturally, then, parent and offspring resemble each other in so many particulars, the bodies of both having really been developed from almost the same material.

If this be a sound conception of the process of heredity, if the sequence of the generations be not from parental body to germ of offspring, but from germ to germ, with the parental body as a bridge or a protective host, performing a temporary service for the "immortal germ-plasm", then we may begin to doubt whether the accidental happenings to that parental body can affect the germ-race within it, or

the features of future bodies which may be developed therefrom. Thus, if the parental body "acquires" the character of losing an arm, we need not expect that this accident will affect the germ-plasm, and the number of arms of future offspring, any more than if the parent had lost not his arm but merely the sleeve of his coat. In either case the loss is irrelevant to the history of the germ-plasm which the arms of the individual body (and the sleeves covering them, for the matter of that) exist primarily in order to protect. Very different would the case be if Darwin's theory of pangenesis were true, and the germ-cells were made by contributions representative of every part of the individual parental body; but that, as we have seen, is not the case.

This assertion, that the modifications of the parental body, which is merely the host or trustee of the germ-plasm, do not affect it, and are therefore not transmissible to offspring, was first laid down by the late Sir Francis Galton. This theory is generally credited to Weismann, and undoubtedly Weismann has done the greater part of the work associated with it, as we shall see, but the first denial of the commonly accepted view — which played a large part, we remember, in the evolutionary system of Lamarck — was made by Galton. Here is his own statement, made at a later date, of the view in question: "As a general rule, with scarcely any exception that cannot be ascribed to other influences, such as bad nutrition or transmitted microbes, the injuries or habits of the parents are found to have no effect on the natural form or faculties of the child."

The position of the study of heredity when Galton took up the subject

The reader should note the words "bad nutrition or transmitted microbes", for they indicate two great realms of causation that have been generally forgotten by students and advocates of the Galton-Weismann theory. But we shall see this more clearly when we come to study Weismann's own individual contributions to the subject.

Those contributions depend upon a particular line of research, the microscopic study of germ-cells, which made a new chapter in the study of heredity, and is adding to that chapter today. But first we must deal with Galton's work, his characteristic method, and the results to which it has led. He founded a definite school, which has attained great prominence in London, though not elsewhere, and the members of which are now contributing copiously to the literature of the subject.

When Galton came to the study of heredity, half a century ago, he found it a chaos. A sharp distinction was made between heredity in animals and heredity in man, most authors admitting the former but denying the latter. The time was ripe for a fresh start. The "Origin of Species" had just been published, and the importance of the study of heredity had risen accordingly, and it had become of even sensational interest, not least as regards man, whom the Darwinian theory classed definitely with the lower animals. As Galton says, "The subject of human heredity had never been squarely faced, and opinions were lax and contradictory. It seems hardly credible now that even the word heredity was then considered fanciful and unusual. I was chaffed by a cultured friend for adopting it from the French."

The incalculable service of Galton's study in calling attention to the question

Galton had himself inherited a strong statistical bent. He liked to reduce everything to numbers, and then study and compare them. His study of heredity was statistical in conception and in detail, and the conclusions which he reached are statistical laws, capable of mathematical expression. His service to the study of heredity, by his interest in it and the discussion his work aroused, is incalculable, but we must pay no reverence to any statement or theory which proves to be erroneous, and unfortunately time has played sad pranks with the greater part of Galton's work, chiefly owing to that of his contemporary Mendel, who was born in the same year, 1822, and to whom he paid generous tribute.

We have already seen that it is all-important, in our study of heredity, to distinguish between true variations, which have their origin in the germ, and the mere results of the interaction between the individual and the environment. Those results may alter the individual in various ways, including the chance of modified nutrition, and of infection with microbes, so that the individual's relation to his offspring is different from what it would otherwise have been. But while these particular differences wrought in the individual are important from the point of view of his offspring, neither they nor any other "acquired characters" or "functional modifications" have any bearing whatsoever upon his actual relation to his ancestors. In studying, then, the measure of likeness and unlikeness between any individual and his or its ancestors, we absolutely must exclude the influence of environment upon the individual. That may be somewhat difficult, but if it is not done we cannot come to a definite decision as to what heredity is actually doing in the case in question.

Galton's statistical examination of variations to illustrate Darwin's ideas

Now Galton was Darwin's cousin, and his interest in heredity was chiefly aroused by the book in which Darwin had declared the natural selection of small random variations between members of a species to be the efficient cause of organic evolution, and of the adaptation of living species each to its niche in the world. Hence the study, as exact as possible, of these alleged variations became immensely important, and the method of Galton was to attack the problem statistically. Let us have large numbers of individuals measured, in various respects, have the measurements compared, and then we shall be able to state a "law" of the distribution of variations. And thereafter we shall be able to see how natural selection of the favored instances among these variations would affect the "origin of species". Such were the lines of reasoning of this investigator, one of the last of the great English non-professional men of science.

The Galtonian mistake of including variations that were not transmissible

But if the mere results of external accident, as regards a thousand factors, are not transmitted by heredity, we shall make no useful contribution to anything unless we are quite certain that the random variations we study and measure are genuine germinal variations, inherent and therefore transmissible, instead of being superposed from without, and therefore shed with the shedding of the individual as the race goes on. And that is where all this enormous mass of work has broken down in recent years. The workers have done everything else, but they have left undone what was really the first task of all, which was to prove that the differences they observed were inheritable. We call them "variations", which we have agreed to define as germinal, not "acquired", but if we find that they are not germinal we shall want a new name for them. At first, when their real character was suspected, biologists called them "fluctuating variations", and now they are very generally spoken of simply as "fluctuations".

The danger of resting on names and numbers and neglecting the facts

This is a most instructive chapter in the history of science, for it teaches the old lesson — that we must keep close to the facts unless we are content to go wrong. Names and numbers will not do, if they do not agree with things. The pioneers in this case are not to be blamed, but their smaller followers, as in a thousand other instances. Darwin was a first-hand observer, and made many experiments. If this had been a task for one man, or for ten ordinary men, he would have done it. As it was, Darwin could only collect materials for the future study of variation. It is in the nature of this kind of work to require time, as astronomy does — you cannot observe characteristics of great grandchildren, and compare them with their ancestors, until life has reached them. Galton, also, made many valuable first-hand observations, such as those already quoted, which disposed of Darwin's theory of "pangenesis".

How Galton's followers continued to stereotype his errors of classification

But the followers of these great men went on other lines. They counted and calculated and assumed. To them a variation was a variation, and its transmissibility could be taken for granted. Their great concern was to discover how these variations were distributed, and thence to reckon what effect various degrees of selection would have upon the race; not troubling to remember that the selection of not inheritable characteristics would have *no* influence on the race. Their calculations resulted in a very definite conclusion, which entirely agreed with the assumption of Darwin, that variations occur in all directions. These measurers of life, or "biometricians", as they are now called, showed that offspring vary in all directions from the type of the parents.

"Variation" — only we must beware of the word — was essentially an affair of the law of chance. Curves could be plotted, showing the distribution of variation among the individuals of a given generation, and it could be shown that this obeyed, as a whole, a law familiar to mathematicians.

The futility of laws of average that prove nothing at all

If we examine all the shots upon a target after very many have been fired, we find that they have a "probable error" that can be measured. Most will be near the bull's-eye, and there will be a gradual thinning as we leave it, until we encounter only a stray shot here and there; and we can readily predict, in a simple formula, the proportion of the total number of shots that will probably show any particular measure of error from the straight path to the bull's eye.

Now it is a fact, statistically proved by these students, that if we examine a very large number of peas or people, leaves, hairs or almost what you will, this law is illustrated by them. There is a sort of average or mean for them, and the further we depart from that, on either side, the fewer will be the number of individuals represented.

Laboratories of life into which no living creature was taken for observation

All this, when studied in detail, becomes very interesting, and is found to be perfectly true. It is exactly what is required for the theory of the origin of species by the natural selection of minute variations which favor survival. Distinguished mathematicians have constructed elaborate and consistent theories of the details of organic evolution, supposed to occur in this fashion, and Galton himself was unfortunately misled, making no experiments in the later decades of his life, and devoting large sums of money to the establishment of "laboratories" for the study of life into which no living creature is ever taken for observation.

The rediscovery of the work done by Mendel many years before had led to many indirect as well as direct consequences. One was a sudden revival of interest in actual breeding experiments, which had been astonishingly neglected while men argued and wrangled and reckoned over theories contained in the "Origin of Species". Only actual breeding experiments could really meet the needs of biology. Darwin did the best he could, but for the most part he was compelled to rely upon the statements of breeders of cattle, gardeners, fanciers and others, whose motive was not scientific, and whose training was no more so. Of course, this could not be expected to suffice.

The statistics of variation proved by experiment to be beside the mark

At whatever expense, at whatever cost of time and labor, biologists were plainly required to make breeding experiments, to which there will never be any end, and thus "to put the question to Nature", as Bacon said, definitely and rigorously, so that nature might return definite and rigorous answers. Recent years have witnessed the practice of such experiments, by men of science with purely scientific ends, on a scale which is certainly not one-millionth of what we need, yet which far exceeds anything of the kind ever attempted by man. Since then "everything is different".

The most remarkable and important discovery of all, negative, indeed, yet more important even than the positive results attained long before by Mendel, is that these "fluctuating variations" or "fluctuations", in all directions, with a regular distribution, from the mean or type of the species, *are not inherited*. They are not germinal, but nutritive — dependent upon the relations between the individual body and the chances of the environment, and thus occurring, on the average, according to the mathematical laws of chance. Not being germinal, these variations, so called, are not inheritable, for inheritance, as we have seen, is really from germs to germs, under cover, as it were, of the individual bodies which contain them. The "variations" so minutely studied were only differences between those bodies, and are therefore seen to have nothing to do with the process of heredity, and therefore *nothing to do with organic evolution*.

Dissolution of the theories of heredity inherited from Darwin through Galton

The writer has failed inexcusably if he has not made plain to the reader the fundamental and overwhelming importance of this conclusion. At one touch of first-hand knowledge, rightly obtained for the special purpose in question, the whole structure of the orthodox theory of evolution, built upon numbers and formulæ and curves on paper, is dissolved.

Professor Bateson's course of lectures on "The Study of Genetics" must have given any amateur student of these subjects a series of surprises. Such amateurs, for the most part, are largely interested in the subject from its bearings on religious belief. They have read the works of Haeckel and Grant Allen, Mr. Edward Clodd and Mr. Joseph McCabe, as well as their volumes of Darwin and Huxley; and they have come to the inevitable conclusion that, as against Genesis, Darwinism must prevail. Genesis for them is orthodoxy, the conventional view in which they were brought up; and Darwinism is the heterodoxy, the daring novelty which the champions of new truth must accept. Let us remind ourselves that Darwinism is only a particular theory to account for organic evolution, which is itself now quite generally accepted, and then let us picture the bewilderment of any ordinary well-informed reader of these subjects who heard Professor Bateson's frequent references to "the orthodox theory", "the conventional interpretation", "the views which we were brought up to believe". These references, inevitable and natural, considering the nature of his subject, and before long quite unremarkable to the ears of those who listened intelligently, were not to Genesis, but Darwinism.

Not even the youngest of us were all brought up to believe in Darwinism as the conventional and respectable view of orthodox people; but if we were, it is time for us to make a fresh start. The assiduous and devoted mathematical study of variation, initiated by Galton, and hailed by certain of his successors as conclusive in its proof of the efficiency of natural selection of minute variations in the formation of new species, avails nothing at all in presence of the demonstration by nature, when the question is put to her, that these variations are not inherited.

How the beginning of the study was mistaken for its completion

It is the end of a strange chapter in the history of science, but apparently many years will pass before it is a matter of general knowledge how far biology has gone, in our own century, beyond the furthest point reached even by Darwin.

Here are words written by Professor Bateson in 1909, the Jubilee year of Darwin's masterpiece:

"The 'Origin' was published in 1859. During the following decade, while the new views were on trial, the experimental breeders continued their work, but before 1870 the field was practically abandoned. In all that concerns the problem of species, the next thirty years are marked by the apathy characteristic of an age of faith. Evolution became the exercising ground of essayists. The number, indeed, of naturalists increased tenfold, but their activities were directed elsewhere. Darwin's achievement so far exceeded anything that

was thought possible before, that what should have been hailed as a long-expected beginning was taken for the completed work. I well remember receiving from one of the most earnest of my seniors the friendly warning that it was waste of time to study variation, for Darwin had swept the field."

And Darwin had never even heard of Mendel! One gasps at such blind advice.

So much for the most important fact which research has brought to light since the mathematical study of variation was initiated. Fluctuations are not inherited; and all the criticism of the theory of natural selection, which we have put forward in previous chapters, based partly on the writings of Bergson and partly on other grounds, may be regarded as superfluous from the practical standpoint for the all-sufficient reason that, with the disproof of the inheritance of fluctuations, the whole theory of organic evolution by means of natural selection falls to the ground.

The absence of the absent accounted for, but not the presence of the present

The theory will account for the absence of the absent, because they were not able to survive in the struggle for existence, and that is a most important contribution to our knowledge, but it tells us nothing as to the presence of the present. We may refrain from observing that the origin of variations has to be accounted for, we may recognize the fact of adaptation in fullest degree, we may grant that variations around the type of any species will some of them tend to favor survival, and will therefore be selected for life and parenthood, but when, at this point, we find that those variations, having been selected, are not inherited, the bottom drops out of the chariot of our fancy, and when we pick ourselves up it is not for further adventures in that vehicle.

But if our history of this chapter in biology is to be at all complete, we cannot leave it without reference to two famous laws, or generalizations, which were framed by Galton, and which are still very frequently referred to in semi-popular writings and by the biometricians, though they no longer interest biologists very much.

The arithmetical basis of Galton's law of ancestral inheritance

The first "Galton's law" is also often called the "law of ancestral inheritance". Its author made a study of a very large number of statistical data as to health, eye-color, stature, etc., in several generations of some hundred and fifty distinct families. Then he made a similar statistical analysis of the colors of a large pedigree stock of Basset hounds. And he found that, both for the human beings and for the dogs, the following law could be affirmed: "The two parents between them contribute on the average one-half of each inherited faculty (or character), each of them contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth, and so on, the sum of the series, $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16}$, etc., being equal to one, as it should be. It is a mathematical property of this infinite series that each term is equal to the sum of all those that follow."

The failure of the law when tested by the study of actual cases

In his book, "Variation in Animals and Plants", published in 1903, Dr. H. M. Vernon, a well-known authority, expressed the opinion that Galton's law "renders the whole theory of heredity simple, straightforward and luminous". How times have changed! Dr. Vernon did not then know the fatal objection which experiment was to bring against any theory of heredity that depended in any degree upon the study of characters that are *not inherited*. The first-hand study of the details of breeding, *with analysis of each individual case*, instead of statistical jumbling of all cases in one wild confusion — which looks orderly because it can be numbered precisely — led in half a dozen years to the verdict of Bateson that, "no one familiar with breeding, or even with literature of breeding, could possibly accept that theory as a literal or adequate presentation of the facts." And this was the "law" which a few years earlier had been said to "render the whole theory of heredity simple, straightforward and luminous"!

Little better is the fate which has overtaken the second of Galton's chief generalizations, the "law of regression to mediocrity". This is another statistical assertion, based essentially upon the putting together, which means the confusion, of large numbers of individual *data*, as opposed to the method of analysis of each *datum* separately.

The lengthy literature of Galton's law of regression to mediocrity

Not so many years ago, practically everyone accepted both of these laws of Galton, and based arguments upon them in relation both to natural selection and to the theory of eugenics. But the "law of ancestral inheritance" has had to be abandoned in face of the evidence, and later it has become clear that the law of "regression to mediocrity" must go also. This law asserts that there is a constant tendency for offspring of parents who have varied from the type, either on one side or the other, to return to it. This return is called regression, a very good name for it, and it constantly tends to keep the species along the line of the great majority of its representatives — that is to say, along the line of mediocrity. Thus the offspring of exceptionally tall plants, shall we say, will be taller than mediocrity, but not so tall as their parents; and the offspring of exceptionally short ones will be shorter than mediocrity, but not so short as their parents. Similarly, the children of genius will be clever, but nearer mediocrity than their parents; the children of criminals will be wayward, but less so than their parents.

This "law" can no longer be accepted. The same radical confusion between the truly germinal and the results of environment pervades it. It does not survive the test of experiment. Further — and this is the most unexpected argument — we begin to see that this law, which sounds so scientific and exact, is really quite mystical and unreal. We learn to look at it so from the very first day on which we start our study of germ-cells. We learn that the characteristics of the individual depend on the composition, contents and structure of the germ-cells that make it.

The failure of the law of regression when tested by experiments

According to the law of "regression towards mediocrity" one would have to examine the ancestors of any individual in order to learn its future. If the individual came of parents, say, very tall, whose tallness was the mediocrity of their stock, then the offspring would be as tall; but if the parental tallness were exceptional, then the offspring would "regress" and not be so tall as their parents. In so far as illustrations can be cited for such a theory, they depend upon exceptional nutritive or environmental conditions — *e.g.*, bad nurture stunted the parents, and the offspring are taller. This has nothing to do with heredity, though it looks like an illustration of "regression towards mediocrity". The hereditary or natural characteristics of the individual depend not on the features of the bodies of its parents and grandparents and so forth, as is assumed in the "laws" of Galton, but upon the facts of the actual germ-cells from which the individual is developed. In a word, we have put these magnificent statistical generalizations under the microscope, and we find that there is nothing in them; the microscopic study of germ-cells has shown us their unreality, once and for all.

Here are the bold and unequivocal words used by Professor Bateson in 1909, much criticized at the time, but now hardly noteworthy — so amazingly rapid has been the development of our knowledge. Dealing with the state of things prior to the rediscovery of Mendel — "with the year 1900 a new era begins" — in the last year of the nineteenth century, he says:

"Of the so-called investigations of heredity pursued by extensions of Galton's non-analytical method, and promoted by Professor Pearson and the English Biometrical School, it is now scarcely necessary to speak. That such work may ultimately contribute to the development of statistical theory cannot be denied, but as applied to the problems of heredity the effort has resulted only in the concealment of that order which it was ostensibly undertaken to reveal.

The hopelessness of methods which dispense with great essentials

"A preliminary acquaintance with the natural history of heredity and variation was sufficient to throw doubt on the foundations of these elaborate researches. To those who hereafter may study this episode in the history of biological science it will appear inexplicable that work so unsound in construction should have been respectfully received by the scientific world. With the discovery of segregation — the peculiar behavior of germ-cells, upon which Mendel's law is based, as we shall see — it became obvious that methods dispensing with individual analysis of the material are useless. The only alternatives open to the inventors of those methods were either to abandon their delusion or to deny the truth of Mendelian facts. In choosing the latter course they have certainly succeeded in delaying recognition of the value of Mendelism, but with the lapse of time the number of persons who have themselves witnessed the phenomena has increased so much that these denials have lost their dangerous character and may be regarded as merely formal."

Professor Bateson's strong words justified by subsequent reports of biometricians

Let us praise great men, and honor Galton for having admitted the fact of Mendelian segregation in the autobiographical volume which he published in 1908, three years before his death. But meanwhile his followers have committed themselves irrevocably to methods which their master would now be the first to recognize as obsolete and inadequate; and if anything were needed to justify the very strong words which Professor Bateson wrote, in 1909, regarding the uselessness of methods which dispense with individual analysis of the material, that justification is to be found in the subsequent reports of the biometricians on the influence of parental alcoholism upon the offspring, when they omitted to ascertain, in a single case, whether the parental alcoholism had occurred before or after the conception and birth of the offspring; and on the alleged inheritance of tuberculosis, where they omitted to take into account the fact that tuberculosis is an infectious disease.

Going back to nature the only sound method of biological study

No; the study of living things cannot be conducted by the manipulation of figures and formulæ at a desk. In order to study them one must live with them and watch the details of their lives. We must go back to nature. That is exactly what biology, all over the world, has done since the dawn of the present century, after very nearly a generation of words and numerals. The nineteenth century was not wholly without men who would not be drawn away from the only method by which natural science has ever taken a single sure step. Darwin, of course, was the greatest of them. He did not sweep the field, but at least he surveyed it.

How the veteran Weismann restored living contact with living things

Mendel was another, but by the accident of the remoteness of Brünn from London or Paris, or even Berlin, his work of 1865 dates, in the development of biology, from 1900, the year of its recognition. Weismann was another, though the work of Mendel, whom Weismann survived by a quarter of a century, is leaving Weismann's behind. But we should not be where we are without the veteran of Freiburg, rightly named August; and his study of germ-cells will restore us to that living contact with living things without which the science of life must ever languish and die. Nay, more; for Weismann has served science no less by interpretation than observation; and, like Darwin and Galton — though all three may now be largely superseded — he put forward clear and arguable ideas, which have stimulated thought and inquiry in every branch of science to new and vital efforts.

GROWTH OF ROOT AND STEM

The Different Forms and Adaptations of Roots and of Stems — Climbing, Twining and Woody

THE THRUST OF LIFE TOWARDS FOOD

WE have now discussed the structure of the simplest form of plant that one can imagine — namely, a seedling. We have further noticed how nutrition is carried on in plant life generally, and the source in nature from which the plant derives its different nutritive materials. And, again, we have seen that this search for food on the part of the plant is not limited to providing for present needs alone, but that it includes preparations for accumulating a sufficient store of food for future necessities. These necessities are of two kinds. In the first place, food is stored up so that the embryo in the seed may have something to fall back upon before it can provide for its own requirements; and, in the second place, food is stored up to enable plants which live for more than one season to utilize a reserve supply during the months of physiological inactivity.

In a previous chapter we observed in some detail exactly how the seedling made its appearance, and we are now, therefore, in a position to devote our attention to what we may term the *physiology* of plant life; in other words, how plants carry out the different vital functions upon which their existence depends. These functions are very much the same in both plants and animals; it is only the means whereby they are effected which differ very markedly. The two primary functions of plant life — apart altogether from reproduction — are the questions of feeding and breathing; and it is to the successful carrying out of these forms of cell activity that most of the structures in the plant are devoted.

The question, therefore, which now arises for our study is — how do plants feed and breathe? This resolves itself into an examination of the structures known as "roots" and "stems" and "leaves," and used in feeding and breathing.

The reader will recollect that these three elements are precisely those which first of all made their appearance in the developed seedling. The radicle emerged from between the cotyledons, and grew downwards, in evident anticipation of the structure and function of roots. The plumule grew upwards towards the surface of the soil, in evident anticipation of the structure of the stem and all its parts. And in some forms of seedlings the cotyledons themselves took on the form and appearance of green leaves; so that root, stem and leaves may be considered as the primary formation of the parts of a plant. These parts, as a matter of fact, are commonly present in all flowering plants.

The primary root of any plant is the ultimate growth of the radicle from the embryo, which, as we have seen, takes a downward course in the soil, growing by means of the cells at its extremity. This growth, however, does not extend indefinitely in this direction or in this manner, because after such a primary root has extended for several inches we may observe that it begins to give off branches, having a somewhat similar appearance and structure to itself, only upon a smaller scale. Moreover, these branches do not grow downwards, but, coming off at right angles from the primary root, they extend laterally, growing, as does the former, by means of the cells at their extremities.

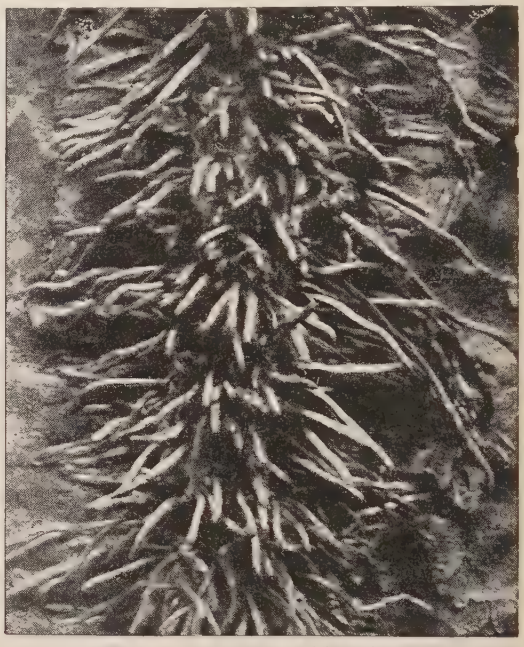
These lateral roots are termed "secondary". In turn, as growth increases, they give off further branches, growing out obliquely from themselves, and these may be termed "tertiary". So this subdivision of roots goes on until we may get a very complicated arrangement, the whole being termed the "root system" of the plant.

The oldest among the primary roots are those which arise nearest to the original position of the cotyledons, and the youngest are those nearest the tip of the primary root, these positions enabling one to determine their relative age. Moreover, they take their origin from within the primary root itself, and are connected with its interior structure.

When the primary root continues to grow prominently, overshadowing in size and strength all secondary roots, we get what is termed a "tap" root, such, for example, as is found in the carrot, and many trees. When the root assumes a more or less irregular, swollen appearance, it is termed "tuberous", and is usually used as a storehouse for food. On the other hand, in many plants the primary root becomes quite overshadowed by the subsequent growth of the secondary and other branches; and when this is the case, the plant, when pulled out of the ground, shows a complicated bundle of roots, all of which are very much the same size and shape, and are spoken of as "fibrous" roots. The common groundsel is an example.

In some other cases the primary root is only a temporary structure, and is succeeded not by branches arising from itself, but by new roots coming from the stem of the plant. Such a case is observed in the onion. Other roots, again, spring from the different parts of the stem of the plant, and even sometimes from leaves, and these are termed "adventitious".

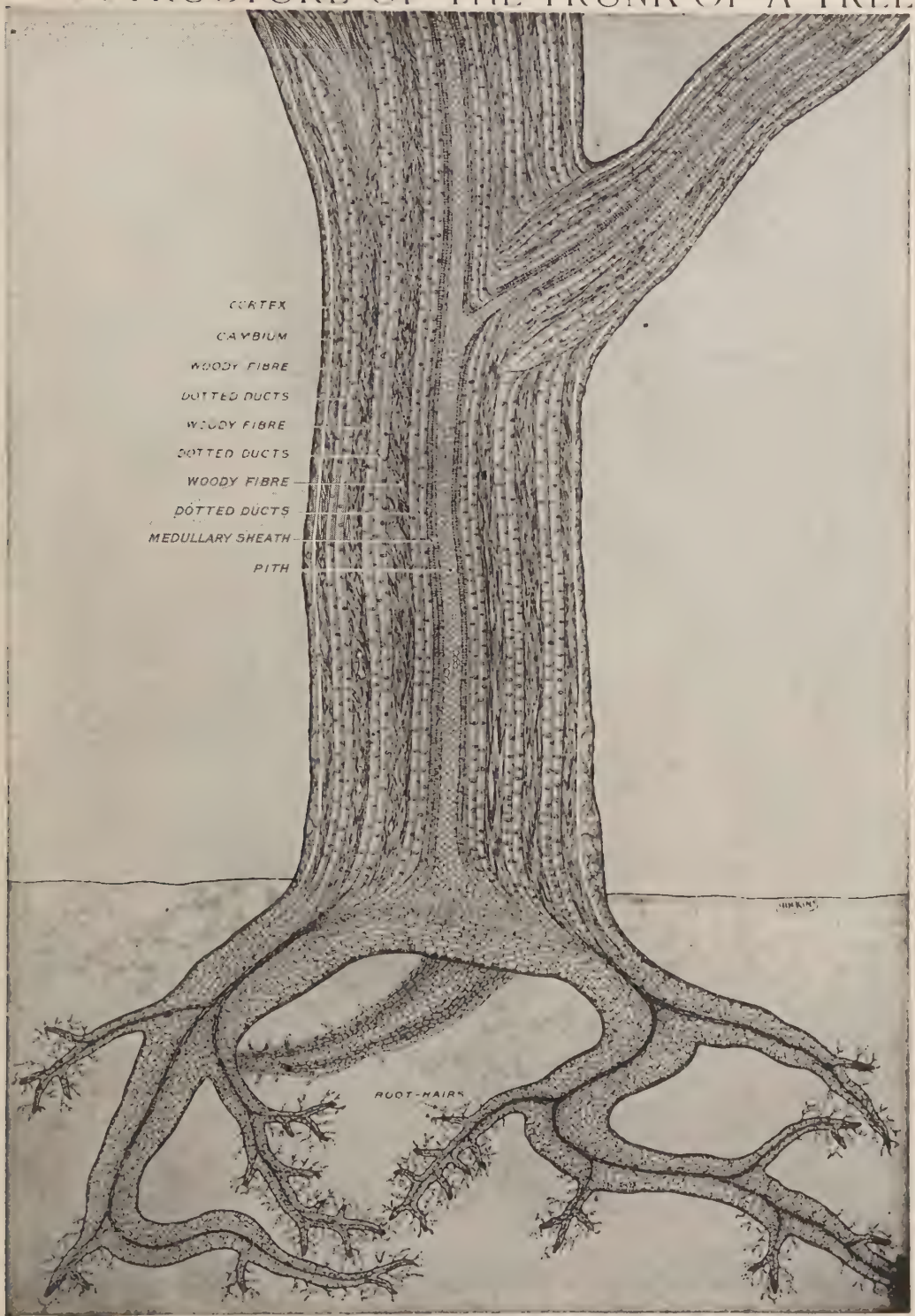
THE FIBROUS ROOTS OF GROUNDSEL



THE ADVENTITIOUS ROOTS OF IVY

Cases of this kind are found among most of the farm plants—for example, in wheat. As we have seen, the embryo of the wheat plant has only three roots, and these are merely of temporary service, being succeeded, by the time the leaves are appearing, by a number of adventitious roots, which take their origin from the lower part of the stem. These adventitious roots, too, are found arising from underground stems, as is excellently seen in the mint plant. The potato is another example of the same thing. They also arise from runners, as is well exemplified in the strawberry plant.

THE STRUCTURE OF THE TRUNK OF A TREE



This picture-diagram of a section through a three-year-old tree shows the various layers that go to make up its stem and insure the stability, growth and nourishment of the tree. The arrows indicate the course of nourishment from leaves to roots and roots to leaves.

All these adventitious roots are apt to occur at the joints in stems, in the same position at which leaves arise, and their appearance is commonly decided upon by the environment; that is to say, so long as the stem is in the air they do not show themselves, but should it come in contact with the soil with sufficient moisture, then they quickly grow. They may, however, arise apart altogether from such circumstances. Nothing is more curious than to observe that these adventitious roots can be made to grow from almost any part of certain plants; and so widely is this recognized that, as a matter of fact, the methods of propagation of many species are determined by this principle. All that is necessary is to take a number of cuttings and place them in the ground, when, climatic and other conditions being favorable, a number of young adventitious roots will make their appearance, and secure food to keep the cutting alive, and ultimately produce a new individual. This is the common way of propagating gooseberries, currants, roses, etc. Such adventitious roots are nearly always of the fibrous nature. Rarely do we find them assuming the tuberous form that is seen in the dahlia plant.

THE LATERAL GROWTH OF THE ROOTS OF A BEECH-TREE
Owing to the hilly situation on which this tree stands, the soil round the roots has fallen away, leaving the root structure bare.

Having been produced in the way above described, the roots of plants and trees spread themselves out in various directions in their search for food; and an example of an uprooted tree will soon show the observer that the growth directly downwards does not extend for any very great depth. As a matter of fact, but few trees send their roots more than a few feet down into the earth.

On the other hand, however, there may be very great extension in the horizontal direction. This is obviously because at a certain distance in the soil the root comes to a region where there is neither moisture nor suitable food. Indeed, the deepest parts of such roots are more for purposes of fixation than nutrition. The latter function is carried on chiefly by means of the fine, small rootlets which arise all over the secondary and other roots, and which are broken off when a plant is pulled out of the ground, their number, on this account, not being readily appreciated.

The condition of the soil will obviously have a considerable effect upon the character of the growth of the root system, apart altogether from the kind of plant concerned. The stiffer the soil, the more compact will be the root system; and, on the other hand, in a very loose and sandy ground the roots will spread far and wide. Adequate fertilizing, too, produces an extra supply of roots, so long as this is not carried to excess.

The different kinds of root, associated with different species of plants, call for close attention on the part of the grower, in so much as the method of tilling the ground, or preparing it, will have to vary considerably to meet the kind of root system in each case. Roots which go to considerable depth will obviously require that the soil should be worked in proportion, whereas roots which are mainly of the surface type can be dealt with on a soil of a much thinner character.

Perhaps the most important structures of all in connection with roots are those which are termed "root hairs". These are not found at the extreme of the growing point, but at a short space behind it. They are always found in this position, and they occur not only upon the primary roots but upon the secondary and other roots, as they make their appearance. They are most plentiful on roots in a moderately damp situation. Their structure is that of hollow tubes, and they are actual outgrowths from the body of the root itself. They have a most fundamentally important function in the physiology of the plant — namely, to absorb from the surrounding soil the water which is required for the cells of the plant, and the dissolved materials in it. They come into closer contact with the soil than any other parts of the underground structures, and are destroyed when a plant is torn up. They are so delicate as to be almost impossible to be seen with the naked eye, and yet are not less important than any

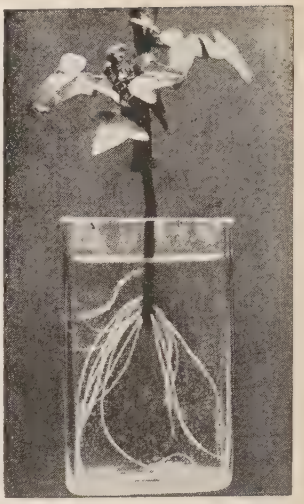
From Lyon's *Soils and Fertilizers*, The Macmillan Co.
THE SHALLOW SOIL THAT SERVES THE PINE

part of the plant. Everything that the plant gains from the soil reaches it through these root hairs. Only through them can moisture be taken in, and all that moisture contains (see illustration of root hairs on the next page).

The actual process by which these root hairs are enabled to transport the water and the soil into the tissues of the plant is that which we have already studied under

EARTH CLINGING TO ROOT HAIRS

the name of "osmosis". It is only those cells on the root hairs which come into actual contact with the particles of the soil which do this work of absorption. The rest act as conductors. They move in such a way as to suggest that they are searching for the most favorable points where this absorption can take place, thus penetrating into the small spaces in the soil in which moisture is found. Should they come to a particularly dense part of the earth, or a solid portion, they turn aside and grow round it. If they encounter large grains of soil they sometimes divide, growing round the grain, and, as it were, embracing it. The minute particles of the earth are found attached to these root hairs, and this attachment is produced by a sort of sticky secretion of the external layer of cells on the root hair. Not only, however, do these root hairs act as organs of absorption for the plant, but they are also organs of excretion. Thus carbonic acid passes out from the plant through them into the earth.

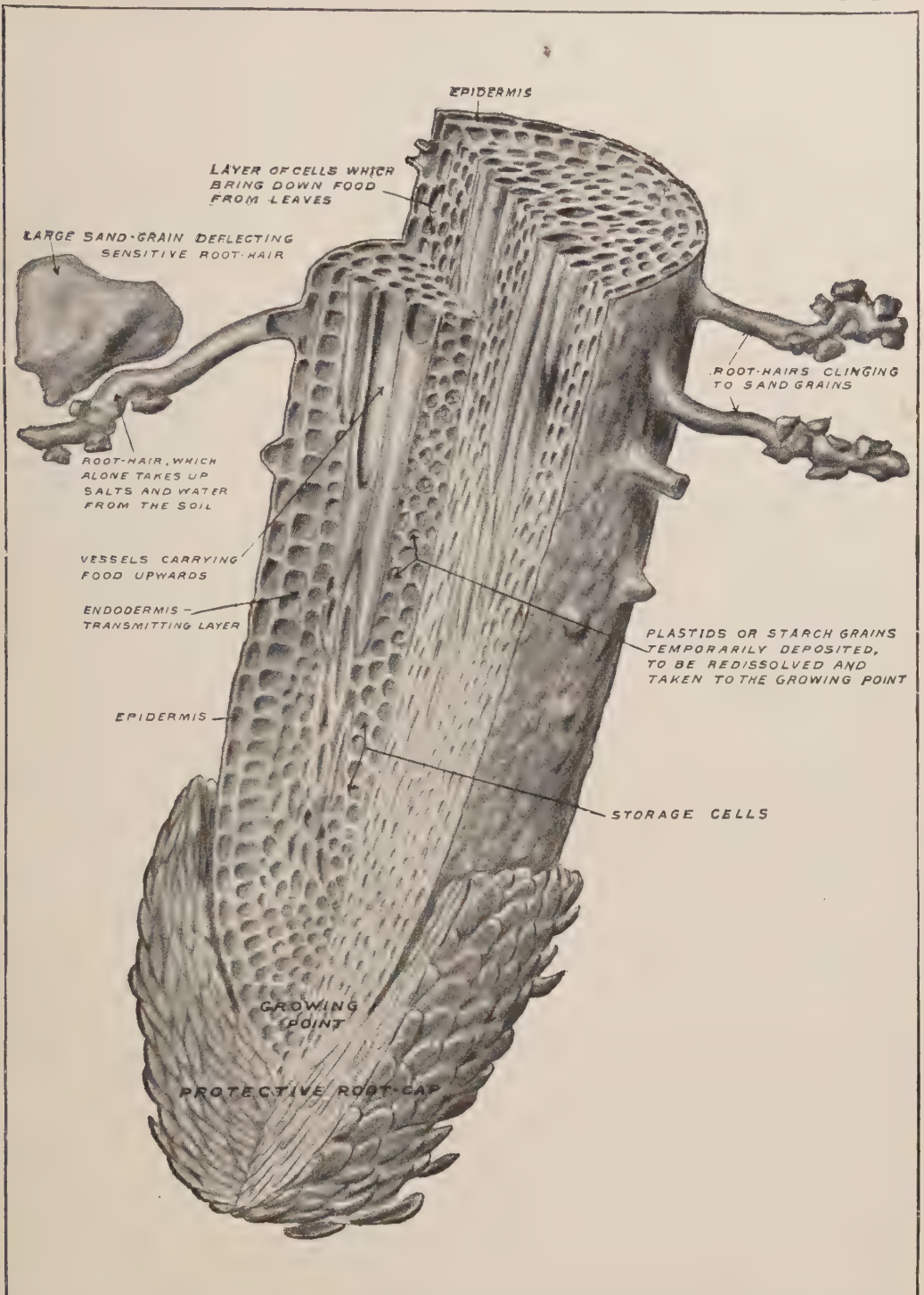


A YOUNG IVY-CUTTING ROOTING IN WATER

It should be noted that these hairs can only do their work in moist ground; and whenever the branches of roots have to make a choice, as it were, between a dry and a moist portion of ground, they invariably grow towards the moist part. This simple fact accounts for the many curious bends, and turns, and changes of direction which can be seen in almost all roots when they are exposed. An examination of any sufficiently deep cutting in the earth will show numerous examples of this fact. The root hairs are constantly perishing and being renewed, and always do they arise about the same distance from the growing tip of the root. They are the more abundant in plants which transpire readily, because in such plants there is a greater necessity to keep up the supply of moisture.

The root, the stem and the leaf are the three essential parts of the plant in connection with the physiology of feeding and breathing. We have discussed the part played in this function by the root, and we must now turn to the consideration of the second of these structures — namely, the stem, since the stem might be defined as that part of the anatomy of a plant which communicates between the root and the leaves, and enables them to work in harmony. It has also, of course, the very important function of elevating the leafy portion of a plant above the surface of the soil into the open air and sunlight, under which conditions alone leaves can best perform their work. The origin and the development of the stem we noticed in connection with the seedling. We must now learn something of the various appearances of stems and their structures, just noting in passing that there are certain groups of plants which have so evolved as to be practically destitute of anything in the nature of a stem at all. These so-called "stemless" plants find examples in the common dandelion, the white clover and many others, which lie close to the ground. This stemless character obviously makes for the protection of the plant, especially from animals which would otherwise feed upon it. Such plants can even be trodden under foot without suffering any very serious injury, and they are therefore enabled to withstand the struggle for existence under conditions which plants with long stems could not resist. As a matter of fact, however, they are not really stemless, but their leaves and flowers come off from a very short stem which scarcely emerges from the soil.

THE BUSY FACTORY WITHIN THE ROOT

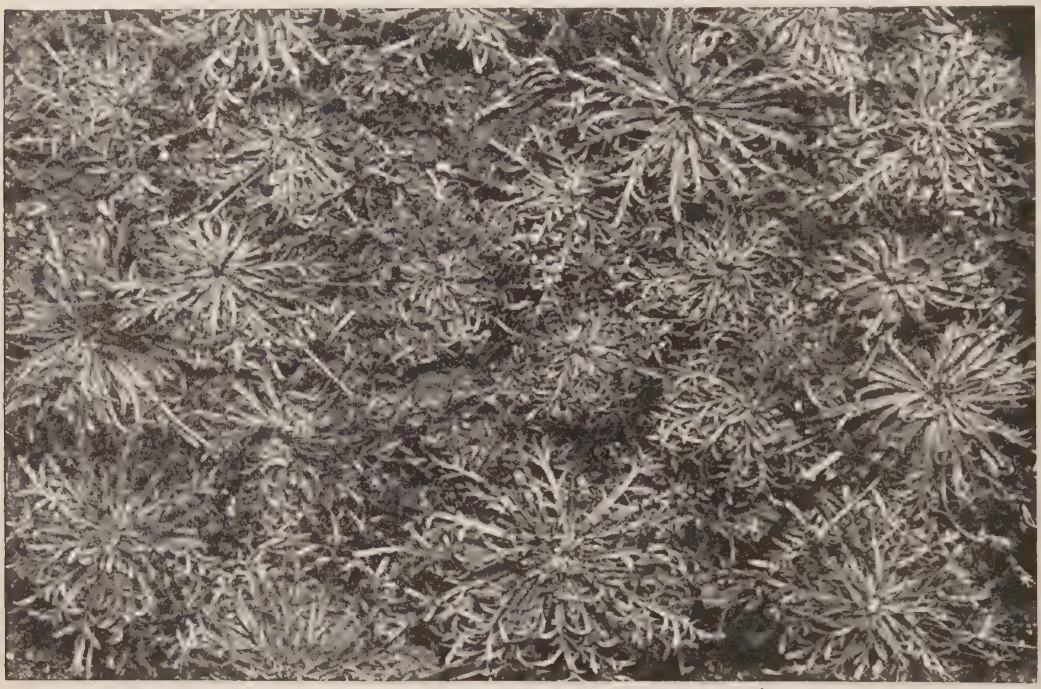

EPIDERMIS
LAYER OF CELLS WHICH BRING DOWN FOOD FROM LEAVES
LARGE SAND-GRAIN DEFLECTING SENSITIVE ROOT-HAIR
ROOT-HAIRS CLINGING TO SAND GRAINS
ROOT-HAIR, WHICH ALONE TAKES UP SALTS AND WATER FROM THE SOIL
VESSELS CARRYING FOOD UPWARDS
ENDODERMIS - TRANSMITTING LAYER
PLASTIDS OR STARCH GRAINS TEMPORARILY DEPOSITED, TO BE REDISSOLVED AND TAKEN TO THE GROWING POINT
EPIDERMIS
STORAGE CELLS
GROWING POINT
PROTECTIVE ROOT-CAP

This picture-diagram shows a root in section, with the various structures named. The cells in the root hairs absorb the moisture from the soil by the process of osmosis, and also secrete carbonic acid, while the cells within the root act as conductors for carrying the food through the plant and for storage.

Nevertheless, it is true that for the best performance of the functions of plants with a complicated structure some form of stem is required, and many and varied are the modifications found in the stems of plants to enable them to do their work under the different conditions in which they find themselves. True, the dandelion and the violet can flourish close to the ground, but most plants require to get some distance above the surface of the soil for their best development, and, indeed, there is evidently a keen competition among many plants to secure the most elevated place within reach. This gives the leaves the maximum of light and air. If plants be crowded together, one can easily observe the effort made on the part of the stem to carry its leaves as high as possible; and in thick woods and forests, where the surface of the ground is always more or less in darkness, we find this principle carried to its limit in the climbers and creepers which, throwing their growing stems from one branch to another, may extend for immense distances before they finally appear at the tops of the trees, and reach the air and light.

It is these climbers and twining stems which best illustrate the special means that stems adopt for their purpose. Three points attract the attention. First, they produce adventitious roots at intervals along the stems, which are used as anchors to support the stem in its progress so far on its upward journey. These roots attach themselves to any suitable object that will retain the stem in position. The ivy plant exemplifies this as it grows up the side of a wall.

Secondly, an effort is made to fix the growing stem by means of special twining branches, or tendrils; and, thirdly, in some cases the entire stem twists about or round and round any supporting structures it can find, as is seen in the case of the hop.



DANDELION GROWING ON A FOOTPATH, HEEDLESS OF MAN'S TREAD

Some of these special forms of stems offer most interesting points for the student of plant life. Thus we find that in those which climb by means of tendrils the tips of these structures move about in the air in various directions until sooner or later they reach something they can lay hold of. They then proceed to coil themselves round this support. The stem goes on

growing, and another tendril goes through the same performance, and thus the stem is anchored at various points. But, still more remarkable, the tendril, having coiled itself round its own point of attachment, may then grow into the form of a spiral coil between that point and where it originates from the stem, thus acting as a spiral spring and drawing the whole stem to the point where the contact of the tendril takes place. This interesting arrangement is seen in the bryony plant.

In the case of twining stems, the end of the stem, which is growing continually, revolves in a more or less circular manner, until it — just as the tendril did — finds some supporting structure around which it can coil. This is one of the most extraordinary examples of actual movements in plant structures that we have. It is excellently seen in connection with the hop plant, which, after twining itself round and round the pole which has been placed in the ground for that purpose, continues to make this circular sweeping movement after reaching the top of the pole. The circle so described by the twining stem is about two feet in diameter. Another plant commonly seen in greenhouses, and known as the wax plant, moves in a still greater circle, of about five feet, and the tip of the stem can be calculated to move at the rate of about two and a half feet in the hour.

We may further note the fact that the same species of plant always twines round its support in the same direction. This direction, however, is not the same necessarily in all species. Some of these tendrils are modifications of the leaf, an example of which may be seen in the pea, where the terminal leaf, instead of being the usual green structure, is modified into a tendril — hence called a "leaf tendril" — very sensitive to anything with which it comes in contact, and readily coiling itself round any available point of attachment. In other cases the tendrils are modified branches of the plant itself, and this we see in the vine and in the passion-flower.

THE TWINING BINDWEED

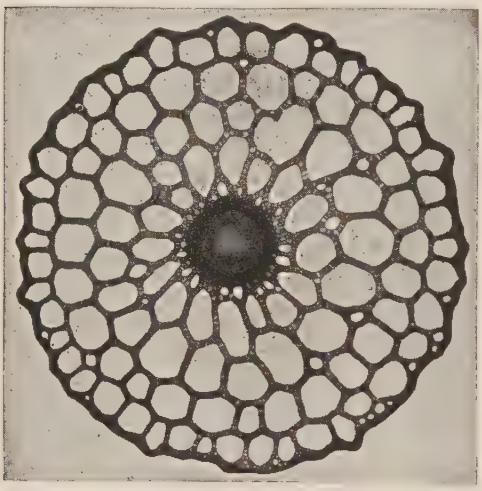
THE TWISTING STEM OF HONEYSUCKLE

The following is a short summary of the different kinds of stems usually found. The "herbaceous" stem is the stem of most of our annual plants, as well as of many perennials. It is a soft structure, lasting

for a comparatively short time. Stems of a more permanent growth must become very dense in consistence, and this they do by producing true wood, and so are termed "woody" stems. Herbaceous

THE LEAF TENDRILS OF PEAS

stems are also composed of wood, but in them it is small in amount in comparison with the softer parts. The distinction between these two is really one of age, not of kind; it is a question of development.



SECTION OF MARE'S-TAIL SHOWING OPEN STRUCTURE OF STEM

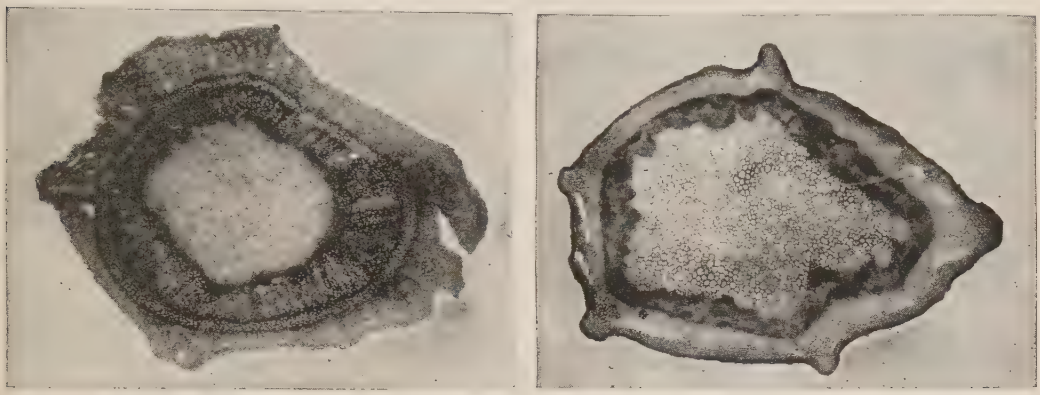
Thus a stem may be herbaceous in its upper parts and woody in its lower, as we find in the wall-flower.

A well-developed stem of the woody type, lasting for a considerable time, is termed a "trunk", such as is found in trees and shrubs. The difference between these two is really one of branching, the tree trunk being free from branches for a certain distance above the surface of the ground. Its woody stem is a prominent feature. The shrub, on the other hand, does not show a very distinct main stem, and its branches, arising low down, are very much of the same size. If the stem is insufficiently strong to raise itself into the air, it is termed "prostrate", while if it develops means of supporting itself in other ways it becomes a "climbing" stem. These supports, as we have seen, are of various kinds, generally termed "tendrils", arising either from the stem itself or from modified leaves. Of the latter kind we have the common tropæolum, the clematis, the peas and the vetches. In the case of the twining stem it should be remembered that it is the whole plant which is coiled round the support. The hop coils to the right, the bindweed to the left.

It is unnecessary here to enter into very minute detail of description concerning the intimate structure of roots and stems. The illustrations in this chapter have been prepared in order to show these points, and a careful examination of them will give the reader a better idea of their intimate structure than mere description.

We have only further to consider at this point what the living parts of the stem actually do, and how the labor of the whole stem is divided among them. This is best studied in the stems of trees. The pith, which forms so large a part of the stems in younger portions of plants, becomes comparatively unimportant later on, though it serves a purpose as a food storehouse. The medullary rays in shoots are the passages along which the moisture and the dissolved food are transferred across the stem, and they also contain stored-up food. The vessels, or channels, in the stem are mainly water-passages up which the moisture travels. The hard, dense portion of the heart of the wood serves the function of maintaining the erect attitude of the tree in virtue of its density. Other cells in the sap-wood, which also helps to support the tree, in addition carry water from roots to leaves.

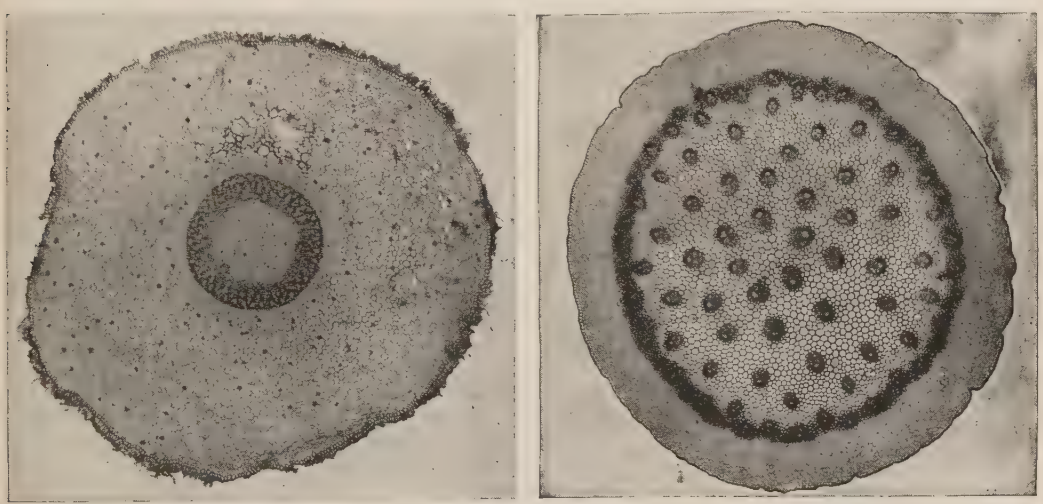
The layer of cambium is that in which new growth takes place every year. But the most important part in connection with the inside of the bark is that in which lie the sieve-tubes. It is through these that the digested food for the plant is transferred from the leaves in the direction of the roots. Much of the nutrient material in the growing portion of the stem is collected by the green layer of the bark, but this process we shall have to consider in connection with leaves in a succeeding chapter.



TRANSVERSE SECTIONS OF THE SOFT AND HARD PARTS OF THE STEM OF A WALLFLOWER

lateral transportation of the fluid from one side of the stem to the other. The causes of these modifications of water or fluid in the stem have been dealt with in connection with the process of osmosis and the phenomenon of root pressure.

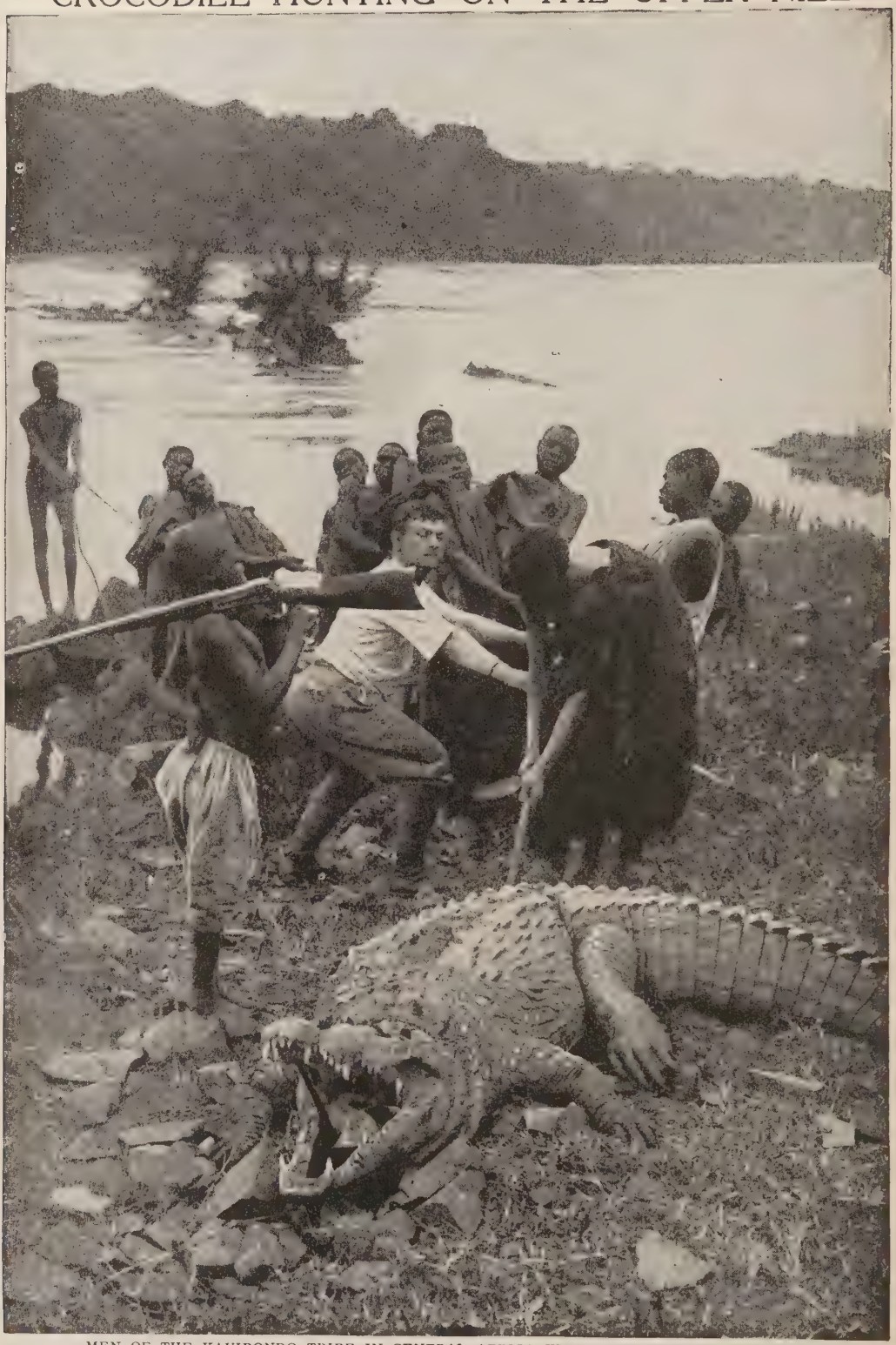
All the most important points in the foregoing paragraphs will be found to be easily understood if a careful examination be made of the illustrations in this chapter, showing roots and stems entire and in cross-section, and diagrams of structure. We would especially draw attention to those which show the different kinds of roots and the way in which the minute particles of earth cling to the root hairs to which they yield up their moisture and other nutritive elements. The other pictures show how these elements are transported throughout the plant.



TRANSVERSE SECTIONS OF THE ROOT AND STEM OF BUTCHER'S BROOM

A considerable amount of water in the form of sap moves by the process of osmosis from the root hairs into the stem of the tree, and rises in the form of crude sap through the newest part of the wood. As a matter of fact, there is both an upward movement of sap, and, in addition,

CROCODILE HUNTING ON THE UPPER NILE



MEN OF THE KAVIRONDO TRIBE IN CENTRAL AFRICA WITH A CAPTURED CROCODILE

ANIMALS IN ARMOR CLAD

Defensive Survivals from the Ages
When Jaw and Claw Ruled the Earth

THE CROCODILE AS A GRUESOME RELIC

EVERY order in life sets out upon its career as a traveler arming for a road beset by bloodthirsty brigands. The process is so old that life may be said to have organized itself into three campaigning groups. One makes attack its means of defense and its method of maintenance of existence. A second trusts to speed, to agility, or to that deceptive appearance which we call "protective mimicry". This, of course, is now the largest group, and is susceptible of infinite subdivision. The third great division lays on armor as if it were a garment.

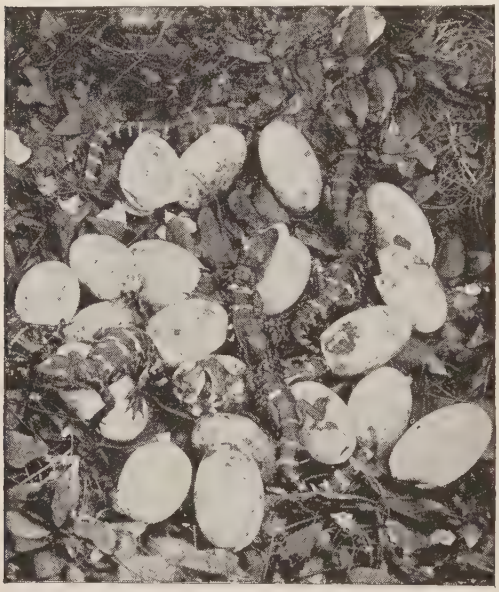
Though placed third in our classification, this group is really a primitive one. When the early animals, waxing mighty in numbers and potent in strength, emerged from the waters to the margins of seas and rivers, and spread far over the land, and the fight for food necessitated the devouring of animal by animal, some defense was called for which ravening teeth and claws could not penetrate. We see today in the armored animals of our own time living relics of that gross and terrific past in which giant brutes, riving and tearing their living prey, parted the planet among themselves.

Nearly every group which can be traced back to its ancestors interned in the rocks is found to have attained either to nightmare proportions or to armor. Most of the animals that retained their armor went out of the plan of existence. Why so many should have perished, while others have remained to flourish in enormous numbers down to our own day, is a problem which considerations of space prevent us from discussing.

Armored animals are more numerous than at first appears, for many types of insects in their coats-of-mail — all the crustaceans, the bulk of the molluscs in their shells, the coral within its defense, the starfish in its limy walls, the snail in its wondrous shell — these are all armored as truly as are the mail-clad sturgeon and the heavily defended garpike, the coffer-fish, and the file-fish. But, numerous as are the animals which have survived by the use of material shield and buckler, they are in a minority as compared with those that have become extinct, yielding place to unarmored descendants for whom activity of brain and limb proved a better defense than the finest mail or carapace that nature ever designed. It will be of interest to consider the defenses and habits of some of the survivors and, neglecting scientific classification, include diverse types.

It is one of the delights of the anatomist to be able to indicate structural features common to birds and crocodiles, but the fascinating fact to the layman is the resemblance between the two in the matter of their birth. Among the members of the crocodile order we have animals which in point of length exceed all other terrestrial animals, snakes alone excepted. Some of them attain a length of between thirty and forty feet, and huge girth and bulk. Yet these monsters lay eggs — forty, fifty, sixty eggs to a nest. In the structure of the heart, and in the beginning of a diaphragm dividing the thorax from the abdomen, the crocodile is more highly specialized than any other reptile, yet it has not advanced to what we call the "viviparous stage".

There are reptiles — the vipers, for example — as there are certain species of shark, in which the eggs are hatched within the body of the parent, but the lord of all the reptiles, the strongest thing in armor, is hatched from an egg laid in an earthen nest, or in rotting vegetation underlying the bushes upon the verge of stream or swamp. Fancy a thirty-five-foot monster, capable of living hundreds of years, and of slaying horse, buffalo, rhinoceros and man himself, issuing from a little pit of sand as the product of an egg no bigger than that of a goose! This is a fact to carry the mind back to the dim and distant ages when fiends in animal form made life hideous.



ALLIGATORS JUST EMERGED FROM THE EGGS

The crocodiles have survived because they remained more generalized than other armored monsters. Their armor is of horny plates, extending from the head to the tip of the tail and, considering the mobility of the animal, this is practically the best form of armor preserved. The crocodile has one disability. Thanks to a merciful limitation, the brute cannot turn its head from side to side, but must charge in a straight line, so that a victim having the presence of mind to circle round the reptile can escape. But despite this limitation the group has long been lord of the places which it frequents. Fairly active on land, and equipped with formidable rending teeth, cunning, invincibly ferocious, and impervious to the attack of any living animal, the members of the order have thriven wherever climatic conditions have rendered it possible. They positively teem in the waters of Central and South America. The Amazon, in parts of its course, is as well stocked with them as a ditch is with tadpoles in summer. They are at once the scavengers and the scourge of the Ganges; they grow to huge size in the Nile, but are now in the lower reaches of the river accessible to the sportsman. They abound in certain rivers of China; they are the curse and horror of certain African rivers. They are one of the indigenous terrors of Australia. In tropical and subtropical climates, given the necessary river, estuary, lake or marsh, they have defied every sort of animate rival throughout their long career.

What has given them this great ascendancy, this hold upon life and power during the ages wherein life about them has changed like the moving color scheme of the kaleidoscope? Clearly armor has been of service to them. No animal can prevail against such an equipment. Added to this is the power of the animal to live either in the water or out of it, a circumstance associated with a highly important fact in regard to the gaining of food. It is not to be inferred that a crocodile can sleep under water day after day, or night by night, never rising to the surface. It is not a gill-breather, of course. But the beast is so fashioned that, while its entire body is immersed, the nostrils, elevated above the rest of the snout, remain free of the water and enable the animal freely to breathe while thus hidden. That is one means by which it is able to capture its unsuspecting prey. But the breathing process is peculiar in more than this respect. The windpipe is not open to the mouth as it is in other animals; it is continued into the nostrils, and can be entirely divided from the mouth. The consequence is that, seizing its prey and dragging it under water, the crocodile can breathe with its mouth open without hindrance from the water by which its tongue and jaws are flooded.

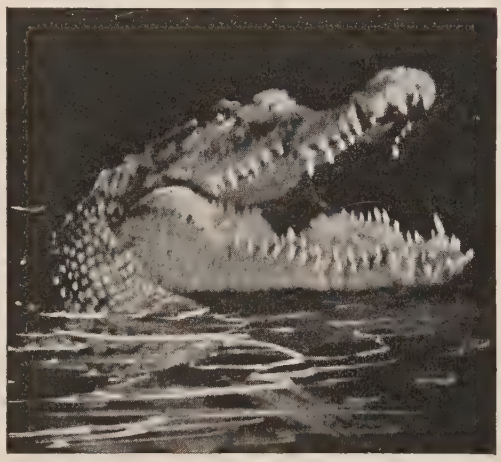
The victim drowns while the cruel teeth hold it under the stream, but the reptile, so long as the tip of the muzzle remains in the air, can breathe with ease. This is a marvelous adaptation to the life which this reptile of the world or waters lives.

The fact is that until the coming of powerful firearms there was nothing to check the advance of the crocodile. From certain points of view it was perhaps as well, for if it took toll of human life, the crocodile also acted involuntarily as a life-saver in that it has been for ages the great scavenger of the waters, consuming for preference the putrid bodies carried down by streams in flood which might otherwise have poisoned man's drinking-supply and spread disease.

So far only the generic name "crocodile" has been employed, but the order embraces half a dozen genera and nearly a score of different species. The caimans are restricted to Central and South America, and are so numerous that the pursuit of them has become an organized industry in Colombia, where as many as 30,000 skins have been exported in a year. Some of the animals attain a length of twenty-four feet, and a girth more than six feet; while their skins of mail, half an inch in thickness not counting the underlying bony protection, when spread out cover an area of as much as eighty to ninety square yards.

The species most sought, however, is the shorter, thick-headed caiman, whose length does not as a rule exceed ten feet; but as it yields excellent ivory in the form of huge teeth, as well as eighty pounds or more of fat from which is obtained an oil used by the natives for medicinal purposes in place of cod-liver oil, and the bones and flesh have a value to the agriculturist, there seems a future for the king of the reptiles very different from that dreamed by the natives whom he has so long terrorized. The caiman is called the alligator, but scientifically the alligator is a genus consisting of only three species; and the curious thing is that one of these, the Chinese alligator, is that which most nearly approaches the American caiman in structural features.

The best known of the alligators is that of the southern waters of the United States, called specifically the "Mississippi alligator". This reptile differs from the crocodile chiefly in the fact that its feet are only partly webbed, and in the shape of the snout which is broad and rounded at the end — not narrow and prolonged. The body is more massive and the weight greater. In the adult the color is blackish green above; but young ones are yellowish with black cross-bands. The nostrils are not elevated, and the alligators spend more time on land than do the crocodiles, lying for hours on some mud-bank basking in the sun; but even the biggest are very timid and quick to retreat to the water when alarmed. One rarely shows

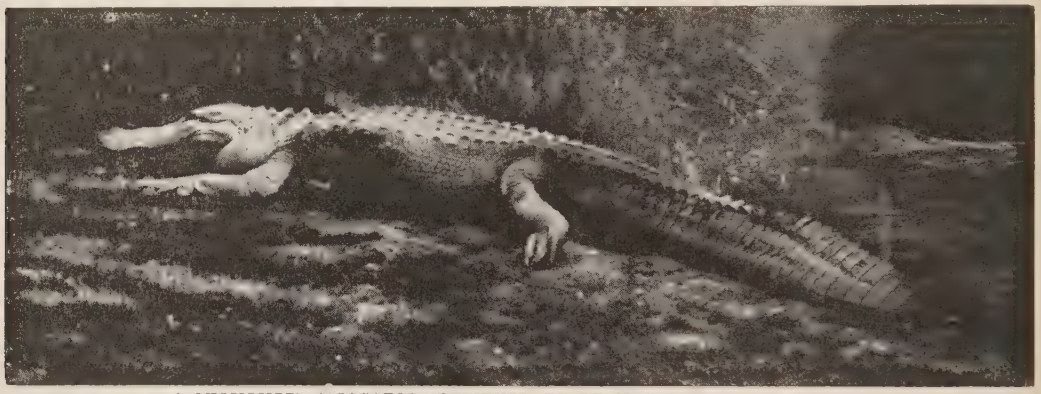


THE TERRIBLE JAWS OF THE CROCODILE

any disposition to attack a man unless he is in the path of escape. Ditmars tells us, indeed, that a man may with perfect safety go bathing in water inhabited by alligators, and feel assured that his presence has inspired the reptiles to place a substantial distance between him and themselves. Nevertheless when cornered, this reptile, which often exceeds twelve feet in length, fights with bold courage and is a formidable antagonist. Its great jaws and big teeth could bite off an arm or leg of a man, and its six or seven feet of tail hurled from side to side with amazing swiftness and force would kill a man with a single fair blow. Yet many are caught with great hooks and dragged ashore and killed, or are trapped in a noose

of rope and bound into helplessness by agile men who know how to avoid their rushes, and dodge jaws and tail. It is said that when a big angry fellow crashes his jaws together it sounds like a stroke on a bass drum. Young ones in captivity are often bad-tempered, but old ones, such as those in zoölogical gardens, become tame and are not feared by their keepers.

This alligator formerly was abundant in the coast rivers and inlets from North Carolina to the Rio Grande, and up the Mississippi and its tributaries as far as northern Louisiana; now it is confined to the rivers and swamps of Florida and the Gulf Coast, and its numbers are rapidly diminishing. This is due to incessant hunting to kill them for the sake of their hides; to senseless shooting by tourists and passengers on river steamboats, and also to search for their nests to get young alligators to sell to tourists as curiosities. The result will be the extermination of the species within a few years.



A MISSISSIPPI ALLIGATOR, BELIEVED TO BE NEARLY 200 YEARS OLD

The breeding habits of the alligator have been thus described by Dr. Hugh M. Smith of the U. S. Fish Commission: "The maternal alligator in April or May seeks a sheltered spot on a bank, and there builds a small mound. The foundation of the mound is of mud and grass, and on this she lays some eggs. She covers the eggs with another stratum of grass and mud, upon which she deposits some more eggs. Thus she proceeds until she has laid from 100 to 200 eggs. The eggs in the course of time are hatched by the sun, assisted by the heat which the decomposition of the vegetable material generates."

This takes about two months; and a few hours before the young are ready to come out they make a squeaking noise, when the mother comes and pulls the mound to pieces, enabling them to wriggle out. "As soon as they have chipped the shell, the baby alligators are led to the water by the mother, who provides them with food which she disgorges, showing much anxiety for their safety. At this early period of their existence they are exposed to many dangers, being a favorite prey of fishes and turtles." It has usually been stated that they grow very slowly, but Ditmars's specimens grew in five years to an average length of five and a half feet and a weight of 50 pounds. Their length of life is not known, but probably is less than heretofore believed.

The prey of alligators is fish, water-fowl and such small mammals as go into the water or too near its edge, where the reptile lies in wait. It is taken under water to be drowned and eaten; and if too large to be gulped down at once, is shaken or torn to pieces before swallowing.

The alligator has a distinguishing peculiarity in its loud voice, unique among reptiles. The smaller ones make a mooing noise, like a cow; but big fellows roar like a lion, and on a still night may be heard for a mile.

The crocodiles proper are more widely distributed than the caiman or alligator, being found in Asia, Africa and tropical America. Livingstone had many unpleasant experiences with crocodiles, which he wrongly calls alligators, a name also given wrongly to the crocodile of India.

He tells how he saw one of his bearers suddenly seized by one of these brutes in the river Leeambye. The man kept his head, and when the reptile got him down to the bottom of the water, whipped out a serviceable dagger and stabbed his assailant behind the ear — the only spot in which one of these creatures can be instantly killed. But the blow must be delivered by a bullet. In this case the reptile was only wounded. Still, writhing with pain, it released the man and made off at a great rate. But it left wounds upon his thigh which the man would carry to the day of his death.

Certain African tribes have a morbid horror of the crocodile, and if one of their number be bitten or even splashed by such a creature, he is forthwith, with his wife and children, expelled from the tribe. One such unfortunate outcast engaged with Livingstone, but, fearing that the traveler would regard him with aversion and contempt, refused to tell the cause of his expulsion. But it was there, written in indelible characters by the teeth of a crocodile upon the luckless man's flesh.

This attitude of the Africans curiously suggests a survival of animal worship which has its counterpart in India, where terrible loss of human life results from the gharial (incorrectly written "gavial") and the ferocious estuarian crocodile, a brute which ranges from India, Ceylon and Burma to Australia. It is the habit of a certain type of mind to worship the powerful and terrific. Grant Duff found a temple erected in India that had been dedicated to cholera.

Naturally, then, the frightful crocodile is regarded as sacred — as it was in ancient days in Egypt. A typical example is afforded by the little village of Mugger Peer, not far from Kurrachee. Here is a ford at which it was noticed that men, women and children, crossing with their burdens at eventide, were wont to disappear. So a watch was at last set and it was found that the crocodiles which infested this part of the river were the offenders. The government was petitioned to intervene not to destroy the animals whose crimes had made them sacred, but to restrain them. So the crocodiles of Mugger Peer are to this day restrained — inclosed, so far as this ford is concerned, by high walls. But the largest and most ferocious brute the people worshiped with particular fervor. He was the rajah of the crocodiles, they said; he must be left at liberty. And this course was agreed to on the condition that a sentry kept guard to see that the reptilian rajah did no harm. And a little temple has been erected at Mugger Peer whose congregation make it their business to feed the crocodiles that they may not suffer hardship for the loss of the human flesh which they formerly had without stint.

Of course, the tables can be turned upon the crocodile; not only may his skin and his fat be utilized — his flesh *can* be eaten. Dean Buckland was not the last to prove that fact, for after slaying and dissecting a couple of the monsters, from one he cut a steak, and made a dish of it for a dinner party. The guests decided the flesh was excellent, resembling tunny or sturgeon.

Photo C. R. Walter

THE GHARIAL CROCODILE, WHICH CAUSES TERRIBLE LOSS OF LIFE IN INDIA

Though its brains are of the most contemptible order, yet there is deadly cunning in the crocodile's ways as when, seeing a man upon the bank of the river opposite to that on which it rests, it plunges like a fury beneath the water. All is silent, but a keen observer may detect a line of ripples advancing across the water. The brute is rushing along the river-bed to seize the man, who has lost sight of it. The adult crocodile has no enemy to fear except the man with the gun. It has only one friend, and that is the black-backed plover, which, walking unconcernedly into the open mouth of the animal, scavenges without molestation, and warns the reptile on the approach of man with its cry of "Zic-zac" from which the bird takes its name.

Before taking leave of this order we ought to recall the fact that the gharial and the alligator formerly abounded in Europe. This is the more notable from the fact that nowhere on earth today can the two genera be found together. One is restricted to tropical Asia, the other to the warmer latitudes of America, and both are excluded from Africa in whose waters only the crocodile is found. As Owen has written, not one representative of the crocodile exists naturally now in Europe, yet every form of the order once flourished in close proximity to the others in a land that now forms part of England.

We shall meet other armored reptiles at a later stage, but here we pass to an extraordinary development of the defensive principle upon totally different lines.

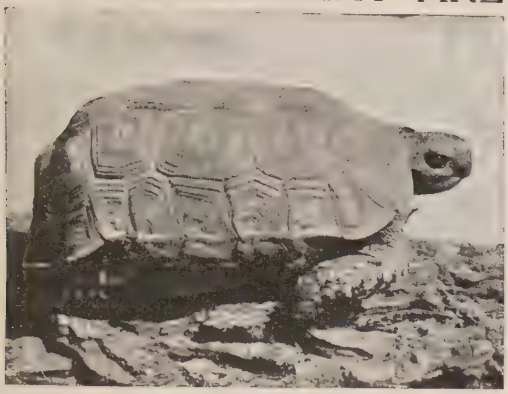
The crocodiles may be likened to armored trains, but the tortoise family are rather perambulating forts — minus guns. We mourn, and rightly mourn, a lost species but this family is witness to the fact that contemporary marvels, so long as they are plentiful, receive not a tithe of the attention that they merit. It is a plain fact that there is not in existence today, nor embedded in the matrix of the rocks, a more extraordinary animal than the tortoise. Here defensive development has reached its most fantastic expression. There is something almost uncanny about the appearance of this animal.

It began, we suppose, upon lines followed by crocodile and many an extinct monster of the sea and land, with a leathery hide in which were embedded various nodules of bone. From these has been evolved one of the most wonderful armaments ever devised. The nodules became plates of bone welded into an impregnable carapace. Superimposed upon this has arisen the beautiful overshield of horn. To attain this the tortoise has, as to most species, sacrificed the skin of its trunk and the underlying muscles; it has forfeited all elasticity of vertebræ between the neck and the tail, and fused these vertebræ into an immovable hollow column of bone, incorporated like the ribs into the fabric of the carapace. It has gradually thrust collar-bone and hip-girdle out of place, so that in the adult these now lie not outside and free of the ribs, but within the cavity which they form. Teeth have gone, and a bird-like beak remains. Breathing is conducted by specialized organs; and in some of the water-tortoises the reptile is developing a fish-like method of supplementing its supply of atmospheric air by extracting oxygen from the water by means of special areas richly charged with blood vessels over which a supply of water constantly washes so long as the creature chooses to remain beneath the surface.

As we all know, there are giants even among tortoises. They were formerly abundant in India, Egypt, North and South America and in parts of Europe, but the advent of man was too much even for the ultimate height of animal armor, and their range became restricted to certain oceanic islands, such as the Seychelles and the Galapagos, where they proved so attractive a diet to mariners that they have been practically exterminated. The survivors should be preserved with care, for man will never again see another such natural marvel.

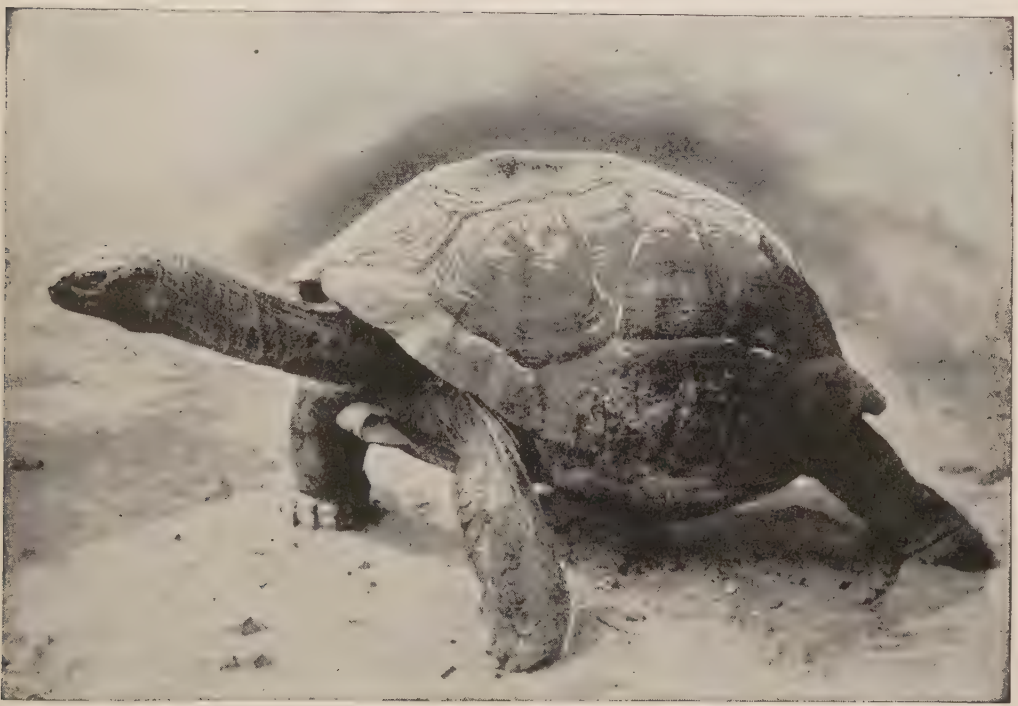
It is common knowledge that a tortoise is one of the longest-lived of animals. One died recently in captivity that was believed to be between four and five centuries old. How long they can live no man knows. The question arises, then, how do they continue to grow for such a length of time without casting their armor?

REPTILES THAT ARE ENCASED IN ARMOR



BELL'S HINGED TORTOISE

CAROLINA BOX TORTOISE



MARION'S TORTOISE, ONE OF THE OLDEST AND LARGEST IN THE WORLD

THE LEATHERY TURTLE

THE TERRAPIN, COMMONLY CALLED "MUD TURTLE"

The scheme of armament is never broken. The bones of the carapace are not one indivisible mass, but are sutured beautifully in such a manner that growth and expansion continually take place. The fortress grows with the garrison. It really is a fortress in the true sense of the word, for there are tortoises that have the lower half of the protecting armor hinged so that at will the head can be inclosed as by an ascending portcullis, while others are similarly defended both fore and aft.

Even so well accoutred a creature as the tortoise must find food; and the stress of life drove early members of the group into the water, where turtles and water-tortoises developed. It would spoil a city gourmand's appetite, perhaps, to tell him that his favorite dish is reptile broth, but his soup is only the stew derived from boiling a sort of water-tortoise which we call a turtle. In this family the legs have become flappers and, correlated with the carnivorous diet, a more formidable beak has been evolved, with which a turtle can snap off the fingers of an incautious man's hand as easily as a land-tortoise can cut a crisp lettuce-leaf. The most formidable of these are the snappers and the alligator turtle, one of the latter having been known to bite a piece out of an inch plank. The tortoise-shell of commerce, by the way, is derived from a turtle, the hawksbill. Disgraceful barbarity was formerly practised in procuring this substance, the shell being burned off the back of the living reptile, but happily that abomination has long been banished and the trade purged of cruelty.

THE SHORT-TAILED PANGOLIN

Photo Lewis Medland

THE HAIRY ARMADILLO

When Frank Buckland was made to pay three shillings and sixpence for the carriage of his monkey which, according to railway regulations, was a "dog" he asked the porter what he must pay for a tortoise. "That's a hinsect and goes free," answered this prime naturalist. What would the glyptodon have been declared in such a court? It was a mighty beast, in a vast bony covering at least six feet in length, and of tremendous weight. Most of us would have been inclined to describe it as a reptile, but in reality it was a mammal, and it has left collateral mammalian descendants in the armadillos of our own time. The glyptodon, the biggest armored mammal that ever lived, was too massive, too immobile. The armadillos have improved upon the older method; they have their fine coat of bony mail, covering the upper parts from the snout to the tip of the tail, but they have their armor hinged, as it were, so that these sturdy creatures can curl up into a ball of armor as neatly as a hedgehog.

Their near ally, the pichiciago, lacks this advantage and, though well armored from buttocks to snout, must remain at full stretch when attacked. There are several species of armadillos, the type culminating in the great armadillo, a mammal marvelously armored, three feet in length, and clad with claws formidable enough to suggest an easy passage into the graves which the animal is accused of robbing.

Two other styles of armament come to mind in those borne by the echidna and the pangolins, the latter well described as animated spruce-cones with head and legs

attached. They are toothless insect-eaters, ants being their chief source of food; but, as prenatal evidences point to ancient possession of teeth, it is believed that the pangolins arise from the same stock as the armadillos.

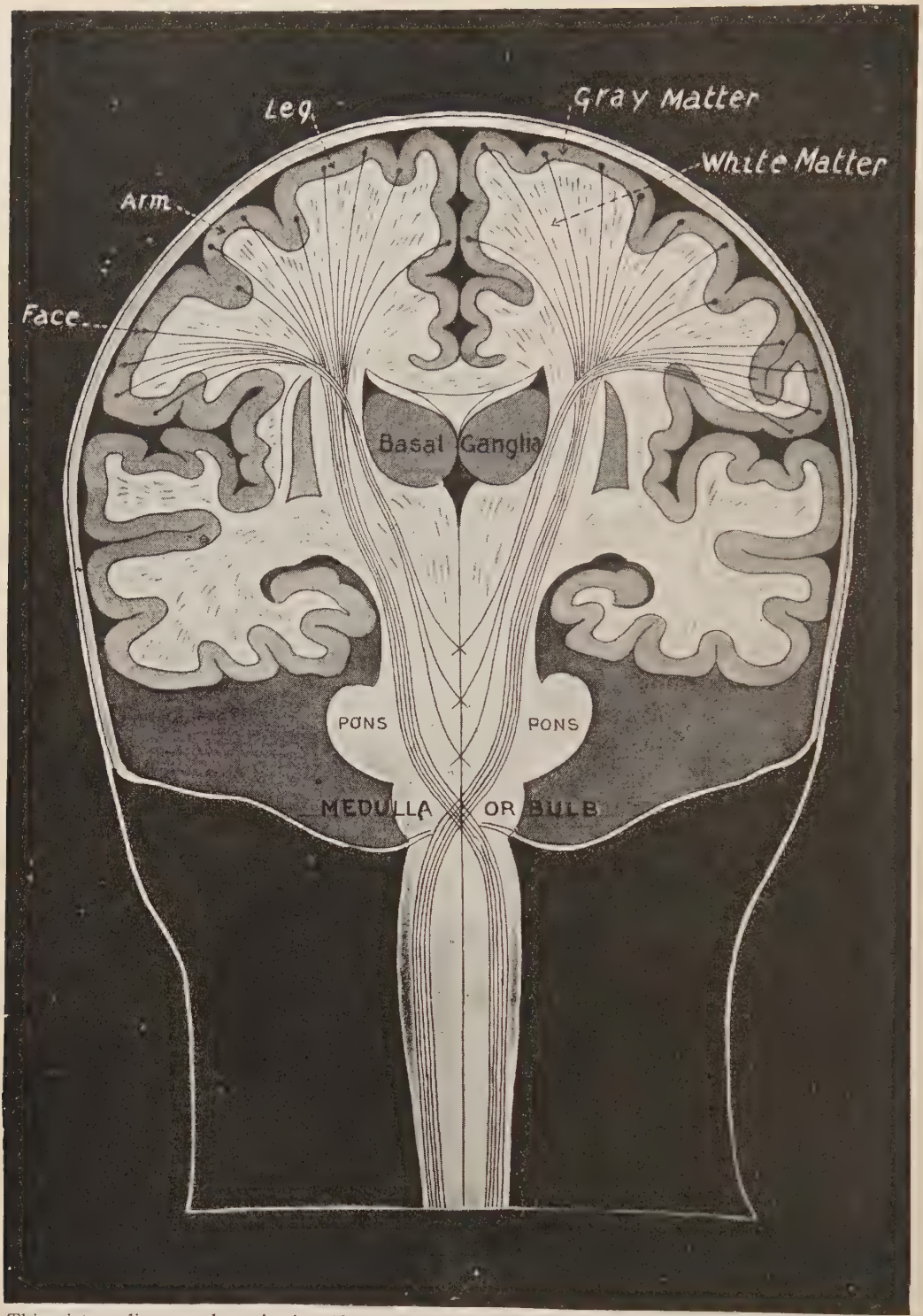
Indeed, the name of the echidna, "spiny ant-eater", declares its characteristics. But though warm-blooded, it lays eggs, and hatches them in its pouch, and then suckles the young — so little and yet so far is it beyond the reptile.

In the armament of the echidna we advance towards another scheme, that of the porcupines. We have finished with plates of bone and horn, and have reached the defense which furnishes means of aggression. Porcupines, whose name really means "spiny pig", are common to both the Old World and the New, and are rodents. They are supposed to be the counterpart in the lower creation of the assegai-throwing Zulu, for nothing will shake the popular belief that the porcupine, when he is annoyed, stands still and bombards his enemy with his quills. Whence the motive-power for the discharge of the projectiles could be derived the authors of the legend omit to inquire. The Canadian porcupine, which has shorter spines than those of the typical group, has these implements short and loosely attached to the skin, so that in a scrimmage they easily become detached and fixed in the flesh of an antagonist. But in the larger porcupines of the Old World — they are found both in southern Europe, in Africa and in tropical Asia — the quills are longer and stouter, and are brought to bear by a wily device.

The porcupine, upon being attacked, keeps his hindquarters toward the enemy and, making a sudden dash backward at him, thrusts his quills deeply into the enemy's flesh. Should any of the quills be loose, they may then remain in the hide of the antagonist, and so support the old story of assault by a battery of quills. The Brazilian tree-porcupine has its spines hidden by hair but, as they are barbed like the spines of certain cacti, no man handles this animal with bare hands. It is a curious but effective defense, a device resembling that of a man the hair of whose head was sown with fish-hooks. The defensive-aggressive quill has succeeded, too, for porcupines are widespread and many. But then the land-tortoise, most immobile of all nature's armed host, is multitudinous in numbers. So are the Crocodilia. Not all the best-defended have perished of inertia.

THE COMMON PORCUPINE

MESSAGE-CARRIERS FROM BRAIN TO BODY



This picture-diagram shows in simplified form how nerve-fibers cross in the medulla, so that the left side of the brain controls the movements of the right side of the body, and vice-versa. These fibers convey the impulses from the surface of the brain to cells in the spinal cord, and thence to the muscles

THE SUPREME ORGAN OF LIFE

The Design and Structure of the Brain, and
the Known Functions of Its Component Parts

A SUMMARY OF EVOLUTIONARY CHANGE

WE have already studied the lungs, the liver, the heart and many other organs of man, and have learned that they exist for his nervous system, and, above all, for the supreme organ that life has created hitherto — that is, the brain of man. This organ is worthy of very careful study by means of dissection and the microscope, for we should not forget that for many long ages, when men argued without looking, they believed that the function of the brain was to cool the overheated vapors arising from the heart — a physiological theory which is still contained in many modes of speech, as when we say that we are "in high spirits".

Only the anatomy of the brain can afford us the clue to its function, and can justify those views of its essential purpose which have already been suggested. We are encouraged by the fact that this organ *must* hold the key, if anatomy holds it at all, to man's place in the world. It is the only characteristic organ of man, being far larger and more complicated in him than in any other creature. It is absolutely the largest brain in the world, even including the whale and the elephant, and, relatively to man's size, it is larger and more exceptional still.

Further, we know that the size of this organ has been increasing, along the vertebrate line of dawning intelligence, for long ages past. If we compare any branch of modern mammals, for instance, such as the horse, the ape, the dog with their remote ancestors, we find that the tendency has always been for brains to beat bulk, brains always increasing while bulk very often decreases. This is the organ of intelligence, and therefore above all the organ of man. It is the highest achievement of organic evolution. We marvel, naturally enough, at the beauty and powers of bird and beast. We almost cower beside the skeleton of the whale. We are staggered at the size of early reptiles and mammals, such as those whose skeletons can be seen in many museums. We envy the dignity and longevity of the mightiest trees of the New World, and the superb chemistry, incomparable in its way, of the green leaf anywhere; but each of us carries inside his skull, and is using at this moment, an organ, a material object, a piece of machinery, which beggars everything, extinct, or extant, that Life has ever achieved since Life began.

The development of the brain in each of us is to be noted. At a very early stage in the human embryo there is a long groove formed along the middle of the back — just where the backbone will some day be. This groove comes to be roofed in, thus forming a long, closed tube, lined, of course, with cells from the surface or ectoderm of the embryo. This is the nervous or neural tube. The cells lining it become, or give rise to, nerve-cells. From these there spring the innumerable nerve-fibers which pass to all parts of the body for various purposes. The back part of the tube, which is the lower part in the erect attitude, remains small and straight. It is the spinal cord, with its tiny central canal, which is the original tube that was formed in the embryo when the neural groove was closed in. Around its central canal we see a multitude of nerve-cells, called the "gray matter" of the spinal cord, because of their appearance. Outside them is a quantity of "white

matter", consisting of nerve-fibers, running up and down in the spinal cord, connecting one part with another. The nerve-cells in the spinal cord are almost wholly concerned with the sensory motor arc which we have already discussed, and upon which psychological theory has asserted the whole of the nervous system to be based. Of all this, which is simple in essence, and is not characteristic of man, no more need be said, except to observe that from each segment of the spinal cord there runs, on each side, a nerve with two roots, and that, as Charles Bell discovered early in the last century, the front or anterior root is wholly motor, and the back or posterior root is wholly sensory. This discovery really laid the foundation for our modern understanding of the nervous system.

The astonishing development of the great brain in man

But as the embryo develops, the head end of its nervous tube develops in marked contrast to the posterior end. It begins to form a series of more or less hollow bulbs, with constrictions between them. The tube is still a tube, with a single cavity, continuous from end to end, but at the head end this tube now consists of quite large chambers, and the nervous tissue around them is very greatly thickened. At one time we can distinguish five of these swellings, at another three. They become squeezed and compressed against each other, as they enlarge, for they have somehow to find room in the skull. But the front bulb is far and away the largest, and there is no room for it any further forward. It has no choice but to fold backwards on itself, so that it comes to lie upon all the other parts of the brain. This front bulb, which undergoes such astonishing development in man, forms the cerebrum, which constitutes by far the greater part of the brain in man, and is its characteristic part. The first appearance and increasing development of this foremost swelling of the front end of the nervous tube, which is the physical counterpart of man's intelligence, can be traced from the earliest vertebrates to man.

The skull's accommodation for the brain a rough measure of mental capacity

In humbler forms the cerebrum is a mere projection from a brain which mainly consists of the nervous centers of vision and smell. Later it has grown, until it begins to turn backwards in order to find room, and thus hides part of the older brain from view.

This process continues until, in the highest animal brains, those of the anthropoid apes, the cerebrum hides the greater part of the rest, when looked at from above. But in man the cerebrum is even larger. The whole of the rest of the brain, with the spinal cord and the sympathetic nervous system thrown in, is dwarfed by it; and when we look down upon the brain we see nothing but cerebrum, all the older parts being hidden and well overlapped by it.

The great size of the brain is indicated by the great size of the skull or cranium of man. The peculiar development of the cranium is forwards, but it is no less notably developed sidewards and upwards, all to accommodate the mighty cerebrum of man. The study of the cranium, or craniology, thus assumes a special importance. The cranium varies widely in capacity in different individuals and races. Skulls can conveniently be estimated as regards capacity by filling with small shot. There *is* a correspondence between skull capacity and brain development, but it is so rough that we must ignore it, though its general significance, when we compare brains and crania, from the fishes upward, is obvious. The attempt to find detailed correspondence between external cranial form and brain functions is, however, hopeless. for reasons already stated.

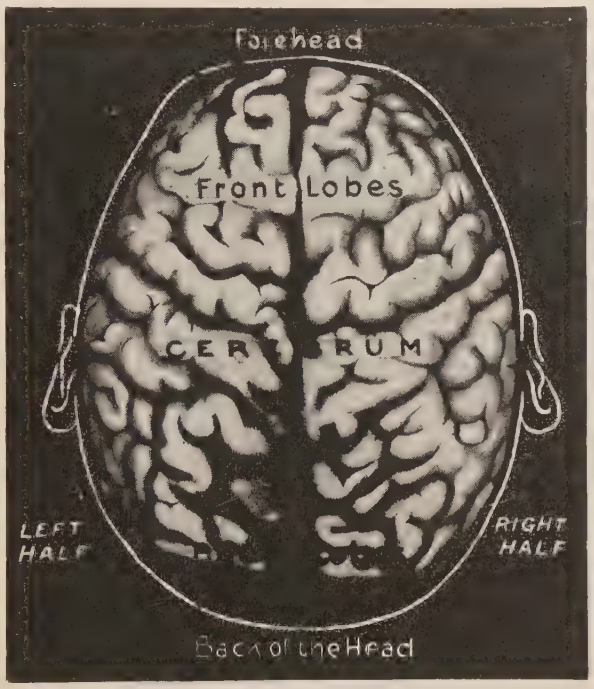
The evolution of the overlaid cerebellum, or little brain

But first of all we must look at the lower parts of the brain, which are essential to life, and indispensable for the operations of the intelligence, though none of them is characteristic of man. Their study in anything like detail is inexhaustible, but the main facts are simple enough.

Note that, according to anatomists, the brain ends at the level of the *foramen magnum* or "great hole" in the base of the skull, where, if the brain ends, the spinal cord begins. The lowest part of the brain is, however, none other in structure than the uppermost part of the spinal cord, and since it is slightly larger it is known as the bulb, or *medulla oblongata*. Above this part we come to another, still continuous with it, which is called the *pons*, or bridge, for a very good reason. First, it communicates between the cerebrum and the bulb and spinal cord. Second, it communicates from side to side between the two halves of a very remarkable part of the brain, called the *cerebellum*.

The cerebellum, or little brain, is easily the largest part of the whole, after the cerebrum itself. It resembles the cerebrum in various particulars but its surface is not so irregular and its markings are more parallel than those of the cerebrum. Its nerve-cells, or gray matter, are on the outside, and its nerve-fibers, or white matter, are on the inside. Its outside is broken up by very deep grooves, so that the surface is really much larger than it would otherwise be, and so its gray matter is proportionately increased. In all these respects the cerebellum resembles the cerebrum, though the breaking up of its surface is much more simple and regular, so that it has a kind of series of leaves, as the accompanying pictures show.

The cerebellum also resembles the cerebrum in the very important respect that it is growing in the course of evolution. It is of unique size in man, but it has also been growing, like the cerebrum, along with the development of intelligence in the course of vertebrate evolution. It is really a very large organ in man, occupying an extensive part of the back of the skull; and there is no better testimony to the amazing development of the cerebrum than that it can completely cover this greatly developed cerebellum, as it does. We may foresee that there is a problem here which merits much further study.



THE BRAIN, SEEN FROM ABOVE

If the upper part of the skull of a man be removed, as in this picture, there would only be seen the cerebrum, or new brain, which has developed so greatly in man that it completely covers the cerebellum.

Packed together at the base of the brain, underneath the cerebrum, and therefore invisible until the brain is taken apart, we find some large masses of gray matter, which are called the basal ganglia of the brain. Their detailed names need not concern us. But we must now try to state the functions of the various parts of the brain that we have named, for there only remains the incomparable cerebrum itself, with which we must hereafter be almost exclusively concerned in the following pages.

The medulla, or bulb, and the pons are simple enough as to function. Like the spinal cord, of which they are really the upper part, they contain a number of nerve-fibers or white matter, running up and down, and, in the case of the pons, also running across. But here we observe a unique and astonishing fact, which no one has yet begun to explain in any credible way. It we trace the nerve-fibers in this region, we find that a great strand of them, the greater number, indeed, cross

over from each side of the body to the other. Why they should do so we cannot say, nor whether the fact may ever give us, perhaps, the key to the historical origin of the central nervous system of vertebrates. But there is the evident fact; and its consequences are no less evident, for it means that, in short, the right side of the cerebrum masters the left side of the body, and *vice versa*. A vast range of knowledge of health and disease, and a great series of possibilities for surgery and for the localization of maladies of the brain, depend upon this simple crossing over of the nerve-fibers from one side of the body to the other in this region.

The bulb and pons, as well as the spinal cord, centers of important nerves

But, like the spinal cord, the bulb and pons also contain within their substance a number of groups of nerve-cells, which are arranged in a series of pairs. These are the centers from which proceed twelve pairs of nerves, which have a variety of functions. These pairs of cranial nerves, as they are called, run to (or from) the nose and the eye, control the movements of the eyeballs, run to (or from) the ear and the organs of balance, run to the muscles of expression, the tongue, and even to the heart and lungs and many of the organs in the abdomen. These last, the organs of the chest and abdomen, are all served by the tenth pair of cranial nerves, which are therefore called the *vagi*, or wandering nerves.

The details of the cranial nerves do not concern us here, but it does concern us that certain of these groups of nerve-cells club together, as it were, according to the destination of the nerves which run from them, so as to form "centers" for certain special purposes of great importance. This is especially true of the bulb, where, as we already know, are found the center that controls respiration — the so-called *punctum vitale*, or "vital point" — the various cardiac centers, the vaso-motor center that controls the size of the blood-vessels, the center for swallowing, a center that may somehow control the proper utilization of sugar in the body, and others besides.

The oldest part of the brain the part least easily endangered

Obviously, therefore, though this is the smallest part of the brain, it is of great importance. It is the oldest part, containing the ancient centers for the control of the ancient functions discharged by organs as old as the heart and lungs. Its stability is great. All manner of poisons and degenerations, senile and other, will affect the later, higher, more delicate parts of the brain, according to the well-known rule of evolution, "last to come, first to go", but the bulb will remain. A man must be desperately drunk before his bulb is affected and his breathing is endangered, though that is the mode of death from acute alcoholism. Insanity or senility may have practically ruined the cerebrum, or, indeed, in idiocy the cerebrum may never even have developed, but the bulb will remain intact, maintaining the purely animal life, though there be nothing else to boast of. Hemorrhage, also, into the bulb and pons is very rare — unless the base of the skull has been broken — and their blood-supply is very secure. The function of the cerebellum has long been highly obscure, and this organ has been deposed by modern science from the somewhat higher place which used to be given it. In the past, men located emotions of various kinds in the cerebellum, including love and hate. But we now know that it has nothing to do with such things.

The cerebellum the organ of balance and mechanical accuracy

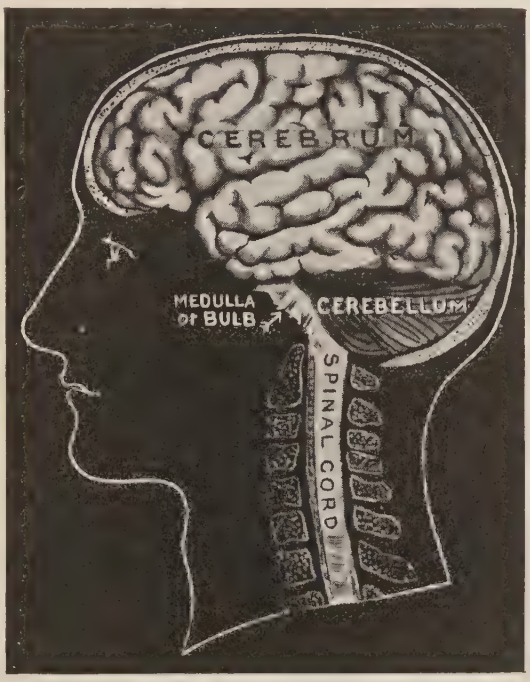
It is, above all, the organ concerned with our control of the body, as regards its balance, its movements, and its muscular habits and aptitudes. If we recall the modern interpretation of the human brain as a whole, that it can learn any habit, make any machine, perform any action, construct *new* motor mechanisms, unlike the brain of any animal, we may realize why the cerebellum is so large in man, and may even realize that, notwithstanding all we have yet to say about the cerebrum, man would not be man even without his cerebellum. In its ordinary

uses, this is the organ of balance. Thus a drunken gait is due to cerebellar poisoning, and such a gait in a sober person is the recognized sign of "cerebellar ataxia", which helps the neurologist to localize a tumor or other malady in that organ. But many other creatures have as much power of balance as man has, perhaps; and we must not suppose that this function is all or much of what the cerebellum achieves, though certainly this is the organ that the dancer, the skater and the tight-rope walker must educate above all.

It is, we may suspect, the organ that forms new motor mechanisms within the body. When we learn not merely to walk, but also to write, to talk, to play the violin and the piano, to sing, to paint, to sew, perform surgical operations, etc. — the list is endless — the cerebellum is being educated; and man has enough to his varied record of achievement for us to be assured that his cerebellum can learn anything he wills it to learn.

He can do what he was born to do; he can improve on this, and add dancing, and skating to walking and running, merely by improving his capacities of balance. But he can do more. He can invent and construct absolutely new motor techniques, like those of the pianist or the surgeon, for his own special purposes; thus we see why his incomparable cerebrum needs an incomparable cerebellum, and why their evolution has proceeded side by side.

The uses of the basal ganglia are not very easily defined. They are very specially connected to nothing in particular, it would seem. Here is a great and complicated mass of nerve-cells, lying at the base of the brain on either side, which are not the obvious "centers" for anything. We do not find pairs of nerves emerging from them, as from the parts beneath them — the pons and the bulb. Nor do we find what the cerebellum shows so clearly — great numbers of nerve-fibers definitely proceeding from cells, and going to definite places. We find fibers from the cerebellum definitely running long distances in the spinal cord, for instance, and forming connections with both sides of the brain in all of its parts. But the nerve-cells which exist in such numbers in the basal ganglia do not send bundles of fibers to various parts in this fashion. They are not motor, like so much of the gray matter we have seen already, from the spinal cord upward, for no motor-nerves whatever spring from them. Neither are they directive and supervisory of motion, as the gray matter of the cerebellum has now been proved by scientists to be.

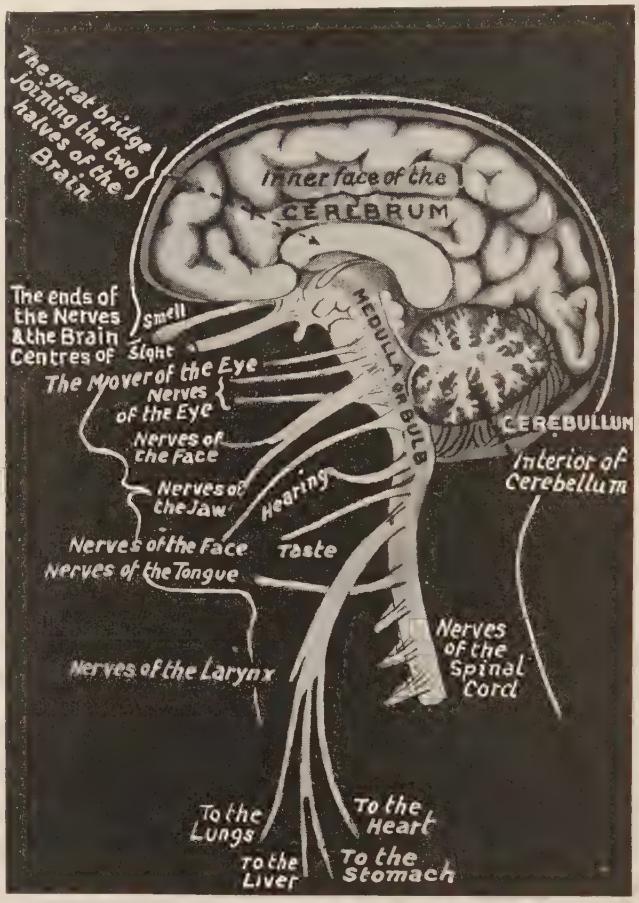


SIDE VIEW OF THE BRAIN

This diagram shows how the brain lies in the skull and the relative positions of the much folded cerebrum, the cerebellum, the bulb and the spinal cord.

If they have nothing to do directly with the motor aspect of the nervous system, they must surely have something definite to do with its other aspect, which is that of sense or feeling. We examine, therefore, the various nerves of sensation to see whether they run to, and really spring from, the basal ganglia. The nerves of sensation are old structures in animal history, and so are the basal ganglia of the brain. We might well expect to find these ganglia the seat of sensation; and there is much reason to suppose that at one time they did serve in this capacity.

But it is one of the most remarkable and significant facts of the human brain that the centers of the various senses — vision, touch, smell and so on, which are exceedingly ancient, and existed in great power for untold ages, are yet to be now found in the cerebrum — and nowhere else. These senses may have had centers when there was no cerebrum; they have centers now in animals that have no cerebrum worth mentioning. Our basal ganglia appear to correspond to such centers, but our senses have gone up higher. No doubt they still have intimate connections with the basal ganglia, and these ganglia may sometimes seem to be a sort of half-way house on the inward path of what will cause a sensation. But the reasoning centers are in the cerebrum; and if we want to know where a touch is felt, though the sense of touch is the oldest we possess, and is found in the amœba, and in every other animal, we learn that the center for the sense of touch is upon the surface of the cerebrum, which is the very latest physical triumph of organic evolution.



A SECTION THROUGH THE MIDDLE OF THE BRAIN

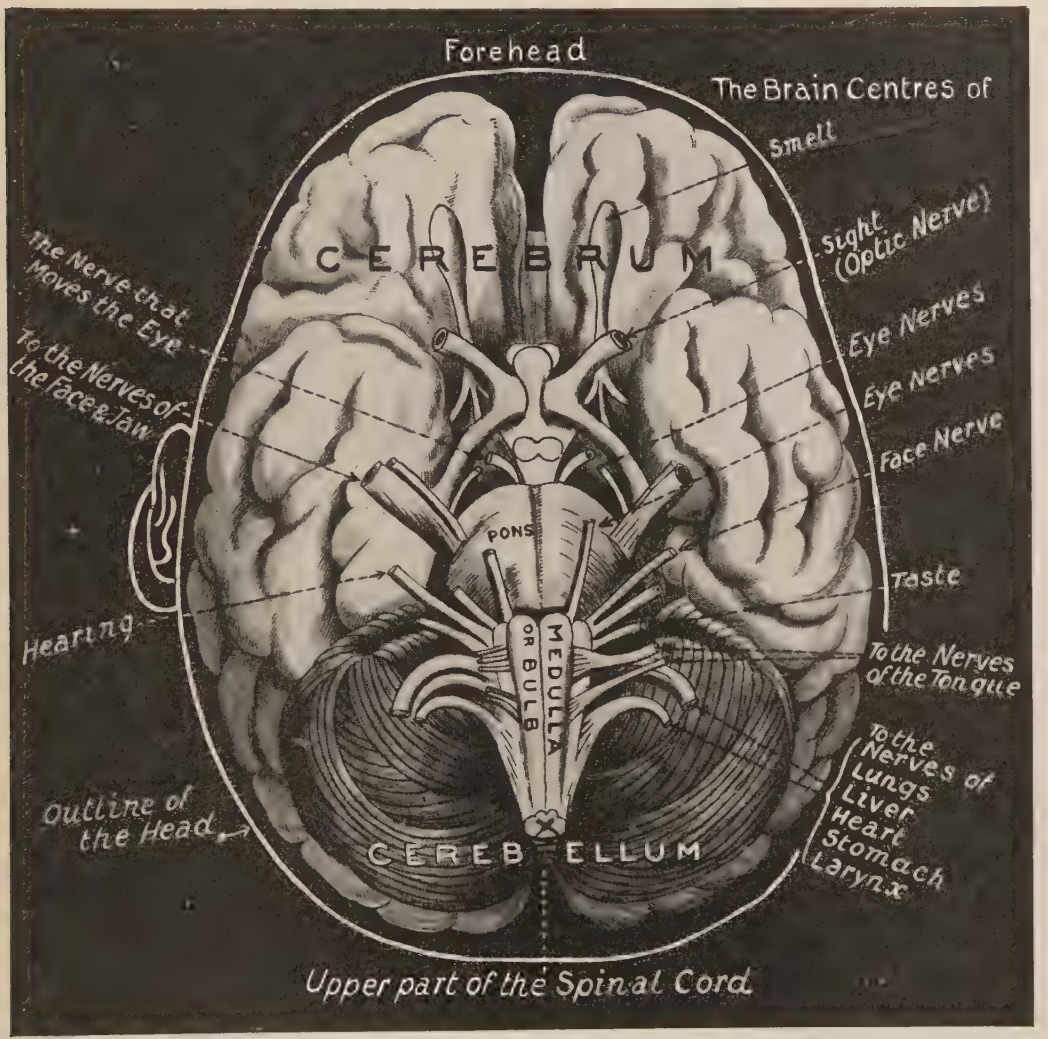
In this picture-diagram of a section through brain and spinal cord are shown the roots of the cranial nerves and the order in which they leave the brain; one only of each pair is shown.

The body has many instances of parts which appear to be useless, but nothing is less probable than that such parts should be found in the brain, occupying any of the priceless room within the skull. There remain two facts at least of the psychical life which we have not yet allocated to any part of the brain — the intelligence and the emotions. We should certainly not expect the intelligence, so recent and rare, to use the basal ganglia, so ancient and common, and least of all when we find that the sensations, which are the data of the intelligence, have left them. But the case of the emotions is very different. Of course, they require and will receive special study, none the less because the old psychology fell far short of doing them justice. But meanwhile we may reasonably state the very high probability that the seat of the emotions in the brain is in the basal ganglia. They must have some seat in the central nervous system, and we can positively exclude all the lower parts of the brain and the spinal cord; likewise the cerebrum — a fact of great importance. Only the basal ganglia remain, and there the emotions must find their seat, unless we accept the very taking theory of William James, that the emotions have no real center or origin in the brain at all, but are only the general effect of certain disturbances of our internal organs; that we feel afraid because we feel the heart palpitating, and not that the heart palpitates because we feel afraid, for instance. If we reject

that theory, as we must while acknowledging some indebtedness to it, we cannot refuse to assign the basal ganglia of the brain to the emotions as their seat and center.

The fuller meaning of this will be realized when we come to see the strict connection between the emotions and the instincts, only perceived by psychology during the present century. We may then incline to the view that these ancient ganglia of the brain are concerned with the organization of the ancient instinctive responses of the living body, as well as with the emotions which accompany them; and we shall understand the close anatomical propinquity of the motor apparatus descending from the cerebrum to these great ganglia at the base of the brain.

Only the cerebrum and its functions remain for our study. But what an "only" is this! For the cerebrum of man is the indispensable instrument whereby he has built cities, written books, conquered the earth, and may even, at the last, become master of himself. The cerebrum is not a creator, but it is the infinite tool of man, the creator. To say

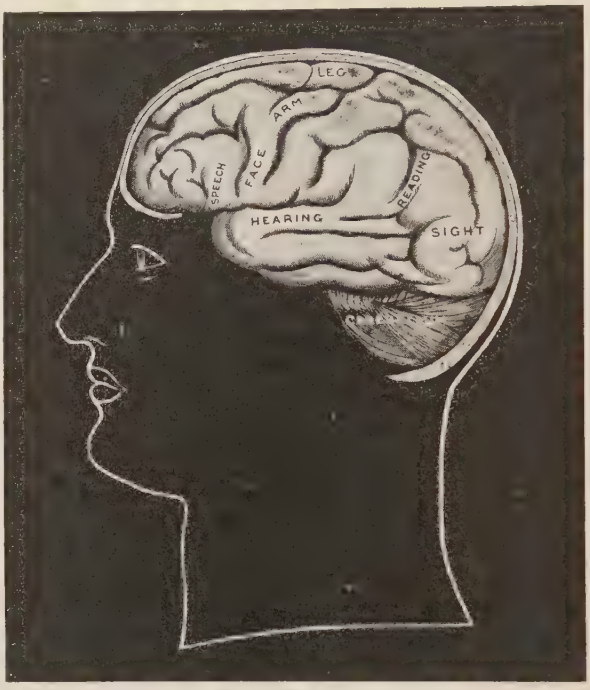


PICTURE-DIAGRAM OF THE BRAIN AS SEEN FROM BENEATH

The entire nerve of smell and the nerve-roots of the other senses and the vital organs are shown in this picture. These nerves are arranged in pairs, two for each sense, and are drawn in the order in which they are attached to the cerebrum, pons and bulb. The crossing of the optic nerves can be clearly seen.

that it alone remains for our study is to say that we have merely now to study man, his doings and his destiny! We shall not leave this subject; and here we must begin with a statement of the main anatomical facts.

This cerebrum is a strictly double organ, consisting of two halves, one on each side, which are connected in various ways. We observed the legitimacy of regarding the heart as a double organ, and speaking of a left heart and a right heart. No less legitimate is it to speak, as we often do for short, of the left brain and the right brain. But the proper designation of these two halves, which we see at once in any but a side view of the brain, is the *cerebral hemispheres*—the two hemispheres of the brain wherewith man has conquered the two hemispheres of the earth. Ideally, so to speak, they are symmetrical, but we find that, in the right-handed adult, the left hemisphere is always slightly the larger of the two, and conversely in left-handed persons. We shall find, also, that on critical examination of the functions of the hemispheres, this disparity is found to be far more marked, one or other being the "leading half" of the brain in everybody, and discharging exalted functions, such as speech, of which the other, the "led half", is incapable. But historically and ideally the two hemispheres are symmetrical; and this we observe directly we begin to follow the very strange and intricate pattern which they display upon their surface. They are not, however, independent. They can be brought into relation, somewhat indirectly, by means of messages sent down and up to and from the lower parts of the brain and spinal cord; they are connected by tiny strands of nerve-fibers that cross the middle line, but chiefly they are connected by a very large and dense body of nerve-fibers, so firm that it is called the *corpus callosum*, which forms a myriad-fold bridge of communication between the two sides of the cerebrum. We shall find that fibers from every part of each hemisphere run through the corpus callosum from side to side, thus intimately connecting the two hemispheres and enabling them to act as one.



SOME CONTROL-CENTERS OF THE BRAIN

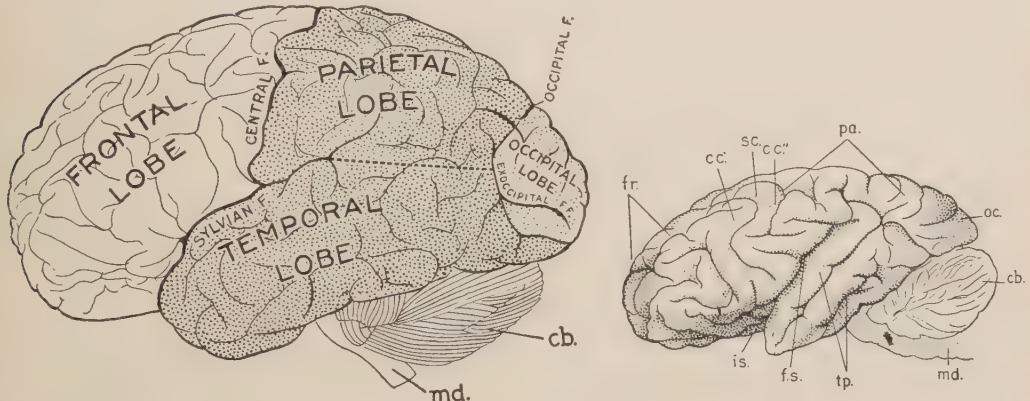
This picture-diagram of the left surface of the brain shows the portions concerned with various senses and movements of limbs. Should the portion of the brain marked "leg" be destroyed, paralysis of the right leg would result.

It is well known that we gain an advantage in seeing with both eyes. Binocular vision gives us a view a little way round an object, and we see its solidity and depth to some extent. Hence, Dr. John Brown, the famous author of "Rab and His Friends", argued long ago that there may be a difference between the kind of thinking that is performed with only one hemisphere and that which employs both sides, so that, as it were, we can think round and see round our subject better. This is at present only a suggestive speculation, and cannot be verified; nor need we necessarily assent to the view that reasoning is performed by interchange of messages between the two cerebral hemispheres by means of the corpus callosum. But it is at least certain, as we shall learn later, that the brain is very rich in association areas and association fibers, as they are called, which

connect different parts of each hemisphere with each other; and the fibers which cross from one hemisphere to the other are evidently part of the general association system that is found to be so marked a characteristic of the human brain. And unless we assume, as some have done, that the "leading half" of the brain does all the thinking and all the remembering, which is highly improbable, we must agree that congenital absence of the corpus callosum, as is found in some defective brains, must sadly interfere with thought, and that it is well to try to use both sides of the brain, rather than one only. But whether this is to be achieved by the cultivation of ambidexterity, and whether it is impossible

water on the brain. But though we must recognize the existence of the central canal of the nervous system, and of the "cerebrospinal fluid" which it contains, and of the ciliated cells which line the tube, we are still uncertain as to all the functions of this fluid, and the spaces, within the cerebral hemispheres, which it fills.

Under the three meninges, or "mothers", of the brain, the *dura mater*, the *arachnoid* and the *pia mater* — "hard", "spider-like", and "tender", respectively, in the old terminology — we come to the surface of the hemispheres themselves; and a glance within shows that the disposition of the nervous elements is the same here as in the cerebellum, and the opposite of



THE SIZE AND STRUCTURE OF THE BRAIN OF MAN AND THE CHIMPANZEE COMPARED

The brain of the chimpanzee is not as long as the human brain and has only about one-third its bulk. Its frontal lobes are less developed, and the cerebrum does not extend beyond the cerebellum. *cb.* cerebellum; *c.c.', c.c.''* anterior and posterior central convolutions; *fr.* frontal lobe; *f.s.* Sylvian fissure; *is.* island of Reil; *md.* medulla; *oc.* occipital lobe; *pa.* parietal lobe; *s.c.* central (Rolando's) fissure; *tp.* temporal lobe.

except for those who have learned to write, and so on, with both hands, is another question which we shall not attempt to decide at present. But we see the anatomical basis for the theory of the champions of ambidexterity.

The cerebral hemispheres are covered with a triple coat of membranes, or meninges, inflammation in which, due to the microbe of tuberculosis, or others, constitutes the well-known malady called meningitis. If this occurs very early in development, and interferes with the circulation of fluid inside the central canal of the nervous system, as it may do by blocking up certain apertures, the fluid increases in bulk, and swells the brain and the head, producing hydrocephalus, or

what we find, for instance, in the spinal cord. The gray matter, containing the nerve-cells, is without, and the white matter, composed of the nerve-fibers, is within. We see, further, a similar arrangement for increasing the surface to that which was employed in the cerebellum. The surface of the hemispheres is deeply grooved with a great complication of branching fissures, or *sulci*, which mark the surface out into a number of folds, convolutions, or *gyri*. The gray matter dips down into the fissures, thereby explaining their presence. If the gray matter of the average brain were to be disposed in its present thickness, upon a smooth surface, the brain, and therefore the skull, would have to be most unmanageably large.

Number and depth of convolutions more important than bulk of brain

The brain has always steadily grown. The earliest cerebrum we know, far down in the scale of life, is perfectly smooth. Gradually the device of infolding has been adopted, to afford a larger surface in the same space. We pass upward through the vertebrate series, and find the head, the cerebrum, and the folds of the cerebrum steadily increasing. The growth of the cerebral *surface* has constantly outrun the growth of its bulk and of the skull. Thus, the fissures are always becoming deeper and more numerous, until we reach the cerebrum of man, in which the hemispheres are fissured to an unparalleled degree both in number and in depth. We may argue that the gray matter might have been made thicker, and it is thicker than it used to be, but evidently there is a limit to useful thickness, and intercommunicating areas of wide extent are preferred. That is attained by thus throwing the surface of the brain into a series of convolutions.

The number and depth of the convolutions vary very considerably in different people, and are undoubtedly related to the quality of the brain, to which they afford a far more trustworthy index than its mere bulk. This fact is, of course, fatal to the pretensions of "phrenology", while it offers the possibility of a new phrenology to which there may be no end. The *extent of surface* gives us, substantially, the *real* size of the brain. Just as comparative and evolutionary study suggests, the fissures are most numerous and deepest in the brains of the higher races, and in individuals of the highest cerebral powers. And agencies, toxic and other, which practically reduce the extent of the brain surface, by destroying the cells which compose it, do directly reduce the mental capacities, as also often the moral capacities, of the affected individual.

The white core of a cerebral hemisphere constitutes by far the greater part of its bulk. The fibers run in all directions, and must be traced, to some extent, when we try to unravel the working of the brain. Meanwhile, we reflect that, for every one of these fibers, there must somewhere be a nerve-cell which nourishes it and employs it, and from which it sprang. The nerve-cells, then, are the essential part of the hemisphere, and we find them exclusively in the gray matter of the surface. In the white core none are to be found. Other cells there are: those which constitute the walls of blood-vessels and lymph-vessels, and also a peculiar type of cell, with many branching processes, which are called *neuroglia*, or "nerve-glue", cells. They are the connective tissue, the "glue", of this part of the body, and are peculiar to it. Everywhere they fill in gaps and hold things together. They look very unlike ordinary connective tissue-cells, and rather like nerve-cells, as if aping the tissue they are made to serve.

But they are really only humble connective tissue-cells, nevertheless, but formed from the ectoderm, or outer layer, of the embryo, and they retain the primitive power of division and multiplication which nerve-cells have utterly lost. Thus, when nerve-cells are destroyed, by poisons or otherwise, neuroglia-cells take their place; and the degenerate brain, perhaps bigger than ever, consists of connective tissue which cannot think, just as the degenerate heart, also larger than ever, consists of connective tissue which cannot contract. Further, we observe that the various tumors of the brain never consist of nerve-cells, which are incapable of forming tumors, innocent or malignant, but consist of cells derived from the neuroglia or the meninges, or some other humble tissue.

And so we pass to the last anatomical unit of the cerebrum, the nerve-cell, as we find it in its millions in the mantle of gray matter that covers the hemispheres and lines their fissures. If we make a section through a hemisphere, at any point, the contrast between the gray surface and the white interior is very obvious. The gray matter is the "bark of the cerebrum", or *cortex cerebri*. It is the essential home of man, his organ of organs, instrument of instruments, becoming more and more the master of all the nerve-cells beneath it, and through them of the external world.

DRUGS: THEIR USES AND ABUSES

The Decadence of Drugging
and the Triumph of the Drug

TEACHINGS OF SUPERSTITION AND SCIENCE

THE reader who thinks that the whole of health is bound up with what one swallows need not fear that we have forgotten diet and its problems, or are going to deal with them perfunctorily. But first we must deal with the question of drug-taking, and note not only its practical importance at the present day, but also the verdict of modern science upon the use of drugs in health and in disease.

It may briefly be said that in our own day the doctors are giving up drugs, and the public is taking them up; they are being abandoned by experience and adopted by ignorance. We speak, of course, of drugs as a whole; the few great exceptions, such as quinine and mercury and iron, will be dealt with in their place. More than half a century ago, Dr. Oliver Wendell Holmes, who was a wise medical observer as well as a humane and illustrious thinker, expressed in characteristic fashion the conclusion to which he had come: "I firmly believe that if the whole *materia medica* could be sunk to the bottom of the sea it would be all the better for mankind and all the worse for the sea." And, more recently, Sir William Osler declared that he is the best doctor who best knows the worthlessness of drugs.

There may be some among our readers who may be inclined to ask what the modern doctor thinks he is good for, if he has no opinion of the medicines he gives. If such a reader were to consult such a doctor, and receive no medicine for his pains, there would be trouble. In fact, the doctor *must* give medicines, for his patients will all leave him unless he does so. If the case is one where available drugs can be of service, well and good; but, if not, the doctor must prepare something or other, preferably with a substantial flavor and smell and color, in order to please the patient.

Very often the drug does good, and is justified, even though any other harmless drug would have done just the same good. The action is through the patient's mind upon the patient's body, a fact of which the patient has no idea; but a faith-cure is none the less a cure, and a much better thing than no cure at all. The sense of mystic comfort which, for most people, attaches to the taking of medicine is beyond question; and it is a fact which the wise practitioner cannot ignore.

The importance of this subject as regards individual conduct also has never been greater than it is today, as every doctor knows. The horrible and offensive drugs used in former days were at least difficult to obtain, and had to fight against the objections offered by the patient's nose and palate. But today manufacturers vie in the effort to turn out drug preparations of the most attractive and tasteless kind, scarcely less tempting than candy; indeed one can now obtain all manner of potent drugs actually inclosed in chocolate and bonbons of various kinds. Hence the universally admitted fact that there was never before so much self-drugging as there is among civilized communities at the present. The drugs simply did not exist, or were not to be had, or cost gigantic sums, in former days.

How drugging arose in the days of medical ignorance

Drugging dates from days when nothing was known about the body, or about disease, or about drugs. That in itself ought to be reason enough for distrusting the practice as a whole; but a far more cogent reason than the ignorance of the past, which invented and practised drugging, is the knowledge of the present, which has studied the body and has ascertained the causes of most forms of disease. Voltaire was fully entitled to his celebrated remark about the doctor of his day — that he poured drugs of which he knew little into a body of which he knew less. The scientific study of drugs was not even conceived of in those days; there was nothing fit to call physiology; and as for disease, it was an utter mystery. Doctoring and drugging were therefore bound to be just as honest and useful as if we should now pretend to doctor bad weather, which we neither understand the causation of nor can control.

The causes of disease were unknown. Thus here was to be seen an ill man who suffered from pain and fever. In the absence of any knowledge of a cause underlying these symptoms — for that is all they are — the symptoms *were* the disease. The body was misbehaving itself in the form of pain and fever. To remove or smudge over these symptoms therefore ranked as curing the disease — until the patient died.

The confounding of the relief of symptoms with the cure of disease

But while these symptoms, wrongly and shallowly described as diseases, were to be met in the sick room, the fields and the woods provided certain plants the leaves or juice or roots of which could also cause remarkable phenomena in one who swallowed them, and such drugs could accordingly be pitted against the symptoms of disease in order to neutralize them, which was called curing the disease, and which is even today the greater part of so-called medical practice. Thus the dried juice of the poppy capsule relieved pain and sleeplessness, which are among the most distressing symptoms of illness, though opium never cured anybody of anything yet; and the leaves of the foxglove would slow down an unduly rapid pulse, though foxglove, or digitalis, valuable drug as it is, never yet cured a diseased heart. These are typical and long-standing instances of vegetable therapeutics — the most ancient form of medical practice in the world, now reduced to the smallest proportions on record in the practice of the leaders of medicine.

How plants strive to repel their own enemies — not man's

There is no good reason, let alone any inherent necessity, why the active medicinal substances found in the vegetable world should serve ailing man. The probabilities are all the other way. Most of these medicinal substances, found in and made by plants, appear to be either poisonous by-products of the plant's own life, which it is in process of destroying, or else poisonous substances which it has produced to protect itself from the animal world. Thus the delicious volatile oils which furnish the finest odors are probably produced by the plant in order to warn off objectionable insects, or to destroy them if they approach; and a nauseating leaf does not constitute a thoughtful vegetable anticipation of the occasional emetic needs of man, but a means of insuring that the animal which seeks to make a meal from such a leaf shall studiously permit the tobacco plant, let us say, to grow in peace for the future.

In point of fact, the vegetable world has been ransacked, for ages, in all parts of the world, and everything, or nearly everything, has been tried for the cure of disease. Weighed and found wanting is the almost universal verdict. A mere modicum of drugs remain that have useful actions of one kind or another. Most of them are useful, not on account of anything they do to the human body, but because the very antiseptic substances which the plant uses to protect itself against microbes may be employed by man to protect him against similar microbes.

Quinine the one vegetable medicine that is specifically useful

And, in sum, there is only one human malady, or only one of any importance, for which the vegetable world provides a cure. It is just a chemical accident that the alkaloid called quinine, produced for its own purposes by a particular plant, arrests the chemical processes which serve the life of the animal parasite of malaria.

The fact is that the chemistry of the vegetable world exists for itself, and is irrelevant to our needs. The chances that vegetable products will cure human diseases are almost nil — quinine is just the one exception. But certainly the chances are greater that particular functions of the body may be affected by vegetable products, and thus that many of the *symptoms* of disease may be modified. Thus morphine and strychnine and atropine are often of great use in medicine, though there is no form of disease which any of them cures. The discovery of the real causes of disease, mostly in the form of minute vegetable parasites, has at the same time displaced the vegetable kingdom from the proud place which it has hitherto held in the pharmacopœias of barbaric and civilized peoples alike.

The millions killed for one cured by vegetable drugs

It is, of course, always entirely conceivable that something might turn up which was as useful, say, in leprosy or pneumonia as quinine is in malaria, but that is the utmost we can say; and modern researchers, all the world over, are now engaged in infinitely more profitable and promising directions. On the whole, if we exclude the unique exception of quinine — which might very well have changed the whole face of history if the ancients had possessed it — it is safe to say that for every patient whom a vegetable drug has cured, throughout the whole history of medicine, millions have been killed; and this doubtless remains true even if we leave out of account the awful history of the unholy alliance between alcohol and medicine in the past.

The lost reputation of mineral medicines when tested by experiment

In the mineral world we find a parallel state of things. Iron, arsenic, mercury, sulphur, to choose notable examples, certainly have their uses, and doubtless always will have. Iron in certain forms of anæmia, mercury in syphilis, sulphur in many parasitic diseases of the skin, are not to be denied the title of cures. But on the whole the drugs derived from the mineral kingdom are in a state of decadence in modern scientific medicine. An excellent illustration of this is furnished by the drug antimony with its various medicinal preparations, which were popular for so long. Like all other drugs, antimony has had to face the tests of modern science, and it has been found wanting. It depresses the essential functions of the body, beginning with the heart, and is probably worse than worthless in all conditions of disease.

Pharmacology is the name given to the science which has changed the face of medical practice in such respects. Its province is the action of all imaginable drugs upon the *healthy* body of man and animals (for there is all the need of veterinary medicine to meet as well). Formerly the action of drugs was only inferred from what appeared to happen in disease. Practically nothing could be so learned, and most of the positive conclusions reached under such hopeless conditions were wrong. Thus, the great heart-stimulant foxglove, or digitalis, was introduced and used for many years as a heart-sedative, because it slowed the pulse in the supposed over-action of fever. All this was wrong. The heart in fever is not overacting, but it is poisoned, and is beating too fast because it cannot beat strongly enough; and the action of digitalis is to strengthen the beats, and therefore reduce the rate of beating that was formerly necessary. Similarly, it is pharmacology that has reversed all the popular and professional opinions about alcohol, proving that the supposed stimulant is a sedative, just as it proved that the supposed sedative digitalis is a stimulant.

On the whole, the result of pharmacology has been to discredit the overwhelming majority of all the drugs used in the past, and to reduce the number of them that are worthy of use to a mere handful. These negative, destructive results of modern knowledge have been especially insisted upon so far in this chapter; but the reader is by no means to suppose that there have been no constructive ones.

For the reader will observe that, besides the vegetable and mineral kingdoms, there is a third, to which we have not even alluded as yet. Might not the animal kingdom furnish chemical resources well suited to serve the needs of such another animal as the body of man? Here is quite a new idea — only that it is also one of the oldest in the history of the medical art. The answer to this question must now engage our attention, and will that of medical science for many decades to come.

The new source of drugs

From the oldest times until the rise of modern medical science, drugs or substances of animal origin had been very largely used by the medical profession. According to the old doctrine of "signatures", one wandered about a field or shrubbery, picking out a leaf of some quaint shape more or less suggesting an animal organ, and then used decoctions of that leaf for supposed maladies of that organ. If that was regarded as sound reasoning, obviously there was something to be said for actually giving doses of the liver of an animal to a human patient whose liver was supposed to be out of order. We must remember, also, the old psychological theories, familiar to every reader of the classics, according to which certain facts of emotion and desire had their seat in certain bodily organs, such as the liver, the kidneys, the "bowels of compassion", and so on. Here, again, was an argument for administering drugs of animal origin to ill people; and if any further motive was needed, there was all the influence of classical augury, in which the entrails of animals were consulted for decisions as to, say, naval engagements and personal matters as well.

All these notions are now simply part of the history of ignorance; and the time came when doctors began to abandon the use of animal drugs, on account of their palpable failure. And if we marvel at their offensiveness, we must remember that disease was regarded as due to possession by an evil spirit, and horrible drugs administered in order to disgust it with its abode, and effect its departure. When the development of modern science, after the revival of learning, began to discredit all such notions, and when the advance of chemistry gave physicians a variety of new drugs derived from the mineral and the vegetable kingdoms, these horrible animal messes were largely abandoned.

Yet, if the reader will remember the scientific argument against the probability that vegetable drugs will cure our diseases — namely, that the chemistry of the plant is irrelevant to the chemical processes of man — he will also see that the chemistry of the bodies of animals must surely be very closely allied in many ways to the chemistry of the human body. We should reasonably expect that, if only the resources of the body of some animal could actually be applied to ourselves, they might, for instance, just contrive to supply a deficiency in our own chemical resources. And that is exactly what has been found.

Consider, for instance, the malady of development which is called cretinism, and also the disease of adult life which is called myxœdema. These diseases and some others are now all included under the excellent general term of athyrea (where the *a* is negative, as in atrophy or apathy), in order to indicate that they are due to deficiency in the action of the thyroid gland in the neck. Once we learn, according to this theory, that certain kinds of imbecility, hitherto absolutely hopeless, are due to defective production of certain chemical bodies by the thyroid gland of the patient, the ancient principles of animal therapeutics, so long dead, spring to life again. We kill a sheep and remove its thyroid gland, which we thereupon administer to the cretin child, and the imbecile becomes educable, intelligent, human. The drug is relevant.

The triumph of the antitoxin treatment in diphtheria, and what it suggests

That was one of the two great therapeutic triumphs of the last decade of the nineteenth century. The other was the antitoxin treatment of diphtheria; and as in the first instance man applied in his extremity to the thyroid gland of the sheep, so here he applies to the blood of the horse. If the poisonous juices, or toxins, of the microbe of diphtheria be brought into relation with the tissues of the horse, those tissues — perhaps the white blood-cells, perhaps something else — produce an antitoxin, which neutralizes the poison; and the production of the antitoxin far exceeds the need, so that in a short time not only is all the toxin in the horse's blood neutralized, but there is also present a great excess of free antitoxin. A child is in the grip of diphtheria, which is clutching at its throat and about to choke it. The child's body is behaving exactly like that of the horse, and producing an antitoxin, but not quickly nor abundantly enough. Let us now reinforce the child's insufficient antitoxin with some of the surplus in the horse's blood. The result is almost instantaneous. The whole meaning and significance of diphtheria have been transformed. The death-rate has been reduced *in exact proportion to the stage in the case when the antitoxin is applied;* no child treated on the first day ever dies, scarcely any treated on the second, and so on. The drug is relevant.

The downfall of drugging and the triumph of really relevant drugs

As long as the maladies due to thyroid insufficiency, or "athyrea", were not understood, hundreds of drugs would be used to combat them, and every new one would be welcomed for its possibilities. Reduce all these maladies and their quite innumerable symptoms to thyroid insufficiency, and instantly you sweep away a shopful of irrelevancies with a single relevant substance.

Let us be clear where we are, and what are the conclusions from our arguments.

Thyroid extract is, of course, a drug. So is diphtheria antitoxin. Nothing could be more untrue than the statement that the most competent physicians use no drugs nowadays or have no faith in them. But it is true that, where their predecessors used scores of drugs, such physicians will scarcely employ more than a dozen, of which, perhaps, neither their predecessors nor the present public have even heard. Again, antiseptic surgery is the triumph of a drug — carbolic acid — but, again, a relevant drug, deliberately selected for its known poisonous action upon the microbes which cause surgical inflammation. Our phrases, then, must be chosen with circumspection; we certainly cannot speak, as some have done, of "the decadence of the drug", but we certainly can speak of "the decadence of drugging". There is all the difference in the world. And if we include among drugs, as we must, the whole series of antiseptics and anæsthetics, together with antitoxins, vaccines and sera, and other substances of animal origin, then certainly the present age of medicine displays what may properly be called the triumph of the drug. Only it is a triumph of this kind — that those who best understand and most profit by it are the most sparing and fastidious and infrequent in their recourse to it.

The body only adapted for the consumption of food — not of drug poisons

The future of drugs, in their scientific employment, demands our attention, and then we shall be fully prepared for the practical moral. No modern physician of the first rank now writes the sort of shotgun prescription with which so many of our forefathers were peppered and slain. We recognize now that any drug must be regarded as a poison until the contrary is proved — and the contrary never is proved. What, indeed, happens is that successive inquiries condemn as poisons many substances which we had supposed to be innocuous, like the boric acid which is added to milk and cream and butter, or was until recently, and the saccharin which people take instead of sugar.

The body is not adapted for the chronic consumption of anything but *foods*. We have learned that even invaluable drugs like quinine are essentially poisons. Metchnikoff insisted upon the fact that this drug tends to paralyze the white cells of the blood; and every doctor knows how liable it is to cause toxic symptoms associated with the sense of hearing. Fortunately, it is much *more* poisonous to the parasite of malaria than it is to us.

The danger that lies in drugs that are really useful

So far as drugs for producing particular effects upon the body are concerned, we have yet to find those which are without risk or danger. The ideal hypnotic, the ideal antiseptic, the ideal anæsthetic, do not yet exist. Those with which the public experiments upon itself so freely do not answer to the description. The antiseptic which is so general in its action as to kill microbes in general is also, and therefore, so general in its action as to kill living cells in general. The public may be persuaded to swallow boasted antiseptics, in consumption and the like, so as to kill the microbes, just as the medical profession ordered antiseptics like creosote for consumption twenty-five years ago. But we now know that, if the general antiseptic is efficient, it is also deadly to the patient's body; and if it is indeed harmless to the patient, it is harmless to his enemies. The future, in this case, lies with the special antiseptics so made as to kill or neutralize special parasites or special poisons, and without any other action. The diphtheria antitoxin is a case in point.

As regards anæsthetics, the public must not suppose that we yet possess anything which is safe for the amateur to employ. People may take chloroform or ether, in small doses, whether by inhalation or by the mouth, for long periods, just as they take the third anæsthetic, alcohol, which is so often combined with them in the "A. C. E." mixture, but doctors know that the effect upon the brain is very serious indeed, and that such treatment is a remedy worth having for no disease or symptom whatever.

There is no ideal anæsthetic or ideal anodyne. We seek in vain for a drug which will relieve pain, and do no harm. Medicine and chemistry know nothing of such a drug, though they know many that may be used with caution, on special occasions, for short periods. But the public assumes that the ideal anodyne, unknown to science, really exists; that it is possible, for a few cents, under any fancy name, to purchase a drug which is so powerful that it will arrest the functioning of an irritated nerve-cell, and yet so innocent that it will do that nerve-cell no harm. The belief is absurd, but thousands of people act upon it every day.

The ideal hypnotic not yet found, and not one fit for the public to help itself to

The case is exactly the same as regards the ideal hypnotic. It does not exist. No doubt German chemistry has done great things in this direction within the last three decades; and in the absence of opium the practitioner is no longer left with chloral alone as a substitute. What we need, however, is a hypnotic which produces the hypnotic effect, and no other, and never loses it. We may yet discover such an hypnotic in the animal kingdom, but meanwhile the verdict, here also, is that there is nothing which is fit for the public to help itself to without medical supervision.

So far as the actual cure of disease is concerned, the future belongs to the animal kingdom, so long neglected; and if we believe in the *vis medicatrix Naturæ*, we can hardly be surprised. The healing power of nature is effected, in the animal body, by animal substances; the thyroid gland will cure or prevent cretinism, the white cells of the blood produce substances that destroy microbes, and so on.

The new medical science simply takes the hint from nature, and applies with intelligence the substances with which she has been preventing and curing disease ever since pain and death first came into the world. This is the proper reply to the unfortunate cranks who inveigh against, say, the antitoxin treatment of diphtheria as unnatural.

The only safe course — not to take any kind of drug without advice

The object of all the foregoing, for the lay reader, has been to justify up to the hilt the practical conclusions at which we are bound to arrive in the interests of hygiene. From the nature of the case, we now see, the drugs which so many of us consume are incapable of curing our disorders, and can, at most, do no more than mask them. Let the reader be specifically warned against all drugs that contain opium, morphine, chloroform, ether or alcohol, even openly, and in small quantities; against the most accursed drug, called cocaine, which is now destroying so many lives in the United States in the larger cities especially; against chloral, chloralamide, trional, tetronal, sulphonal, paraldehyde, veronal and all other hypnotics ending in *al*, or any other terminals; against antipyrin or phenazonum, antifebrin or acetanilid, phenacetin, exalgin, antikamnia, chlorodyne, and their congeners, one and all. The results of taking these things, none of which is a *cure* for any known disease, are only too often horrible in the extreme; and their nature is such that the only safe course is not to begin their use. They attack the centers of self-control or inhibition, and there is little hope or help when these are captured.

The evil of handing prescriptions from patient to patient

Many of these drugs have their uses on occasion; and if they be freely given it is possible for the doctor to gain the temporary gratitude of his patient by their employment, but the risk of prescribing them, except in the most rigidly limited way, is one from which the conscientious practitioner must always shrink. Though they are sometimes useful, so are arsenic and prussic acid, but it is really more necessary that their employment should be limited and under responsible control than in the case of these two notorious poisons. Indeed these, and many besides, should be labeled poisons, which they really are, and should be so prescribed.

It ought also to be quite impossible to repeat such prescriptions without the doctor's order, and absolutely out of the question that the prescription should be handed from one patient to another, for those who have no knowledge at all cannot judge whether the prescription which suits one patient is suitable, or even safe, for another. As for drug habits which have been started in this way, their name is legion.

Curative drugs of the body's own making

So much for those recognized and official drugs, of which the dangers, unfortunately, are so little recognized. And now let us return to the general conclusion which has been asserting itself all along: that the drugs of the future will be obtained from animal sources. We have quoted two great illustrations, and the reader must already have observed that his own body is manufacturing "thyroid extract", that marvelous drug, for itself all the time, otherwise he would either be a hopeless fool, by no means reading these lines, or, if he were producing no thyroid secretion at all, he would almost certainly be dead. Similarly, though his body is not producing diphtheria antitoxin at the moment, that is merely because, in all probability, he is not just now being attacked by the diphtheria bacillus — or it would be doing so. The meaning of all this is clear. If we find that, for drugs that are really worth talking about, we have to abandon the vegetable and mineral kingdoms, and search the animal body, it is clear that the *vis medicatrix Naturæ*, long worshiped by the wisest of the ancients, has taken bodily form at last.

How the healthy body makes drugs to keep its own health

Modern science finds this mystic power incarnate in the living body, and its instruments can be isolated, handled, weighed and tasted. In a word, the really curative drugs are of the body's own making, nor, with a rare exception or two, are they to be purchased at almost any pharmacy. We are only beginning to isolate these drugs, and little enough is known about them.

But at least the modern physiologist knows that the greater part of any serious discussion of personal hygiene, such as this present one, is really concerned with the production and employment of these curative, *and preventive*, medicines in and by the healthy body. The writer of the treatise may not know it, nor may his readers. Yet that is what they are really discussing and aiming at all the time. He tells them to breathe open air, because experience shows its value; but his successors, a generation hence, may be able to isolate from the body the exact chemical substance which is best produced by it under the influence of open air, and which antagonizes disease — say, by making the body uninhabitable by any given microbe. Thus the reader who now attends to the advice already given regarding open air, or on many other points, is favoring beyond a doubt the conditions under which the protective and curative substances are manufactured, dispensed and administered in and by his own body, which is far and away the wisest and most accomplished of manufacturing chemists, and incomparably superior to any doctor in the diagnosis of its diseases and their treatment.

The natural antiseptics which are produced by the body to kill its enemies

All this is so important and so radical in our modern conceptions of hygiene, and so entirely condemnatory of the practice of self-drugging, from which we desire to exclude every reader of THE BOOK OF POPULAR SCIENCE, that a few illustrations must be cited. They range from trifles to the most mortal diseases. Thus, the healthy nose secretes an antiseptic mucus, which largely kills objectionable microbes, such as those which produce a common cold, influenza or pneumonia. The healthy blood contains antiseptic substances which must frequently be called upon to destroy the microbes of consumption. We have evidence that the greater number of all people have been attacked by consumption during the course of their lives, and have rapidly recovered, probably without any idea of what had happened. The recovery was due to the body's own antiseptics. If the doctor tries to add antiseptics to the body for this purpose, he always fails; and on the day on which the researchers isolate, in the body, the substance which it makes for its own protection against the tubercle microbe, and succeed in giving it to patients without destroying its powers *en route*, on that day all cases of consumption will be curable and will be cured.

How the stomach protects itself against infection from living organisms

The healthy stomach — but observe that we speak always of the *healthy* nose, the *healthy* blood, the *healthy* stomach — produces a "mineral acid" called hydrochloric. It is the acid constituent of common salt, for instance, and is really a most strange and surprising thing to find produced in the living body. It is of value in digestion, but it is far from being indispensable for digestion and the kind of digestion which it performs, or, rather, facilitates, is better performed in the bowel with the aid of a powerful alkali. Yet this acid is always formed in large quantities by the healthy stomach, which is richly provided with millions of living cells that exist solely for this purpose. Now, hydrochloric acid is an antiseptic, and has long been known to kill various yeasts and other fungi, which may be swallowed in the food, and which multiply in the stomach, causing tragic dyspepsia if the hydrochloric acid is not properly formed. It is the natural antiseptic of the body, or one of them, for there may well be thousands; and it daily saves us from all manner of infections due to the living organisms that we swallow in all uncooked or imperfectly cooked food.

Spontaneous cures always going on in our bodies without our knowledge

To these instances add the thyroid secretion, which is daily curing or preventing — either word will do — in each of us such diseases as cretinism and myxœdema; the pituitary secretion, which, by its right quantity and quality, is preventing acromegaly; the secretion of the adrenal

glands, which is preventing Addison's disease; the invaluable internal secretions of the racial glands, without which we should not be ourselves. And now authorities on cancer are declaring that probably in very many people malignant growths are started, and then suppressed, by the resources of the body without anyone knowing anything about it; that the healthy body is constantly producing substances which are antiseptic, so to speak, to the cancer cells which would otherwise develop in it, and that the "spontaneous cure" which is sometimes seen in cancer, and is probably far commoner than we know, is due also to the sudden determination of the body to rid itself of the invader. It is along these lines, doubtless, that the certain and constant cure of cancer will ultimately be achieved. Nothing more need be said on that subject now. The point is that, in the whole range of disease represented by the contrast between a cold and a cancer, the same principles are illustrated. It is by its own chemical products, made on purpose, inimitable in fitness, safety, variety, delicacy, certainty of administration, infallibility of diagnosis, that the body keeps itself well, controls insurrection, checks waste, neutralizes poisons, destroys invaders and goes boldly forward, never doubting.

Folly of drenching the body with alien drugs that probably only do harm

That is the conclusion of modern knowledge. That is the fact which modern science seeks to elucidate and modern practice to apply; and in the light of that great conclusion, so new and yet so old, we must approach and censure, almost without reserve, the ever-increasing folly which drenches this house of life, so powerful and delicate, so wise and so heedful, with alien drugs which can rarely do it anything but harm. No doubt a new era is approaching. But our say must be said, if we are to carry out a leading principle of this section, which is to warn the reader against all manner of poisons; for alien drugs in general, like the gases of foul air and the products of over-eating, fall within the category.

How people who drug themselves pay ten times the cost of the drugs they use

Patent medicines are largely consumed by people of small income, and therefore the question of their cost is important. That is the first objection to a very large number of them, of which the only active principle is aloes, and which may often be very useful indeed. The great malady of civilized life among the sedentary is constipation. We shall see, in due course, what are its causes and the proper ways of dealing with it — ways simple and pleasant and certain. But at present the public is not instructed in these matters. The children do not learn about them at school, and, no doubt, the present work involves the most extended and comprehensive instruction of the public in these scientific matters of personal moment that has ever been achieved hitherto. Such being the state of the popular mind, and such being the demand of the sedentary bowel, of course there has sprung up a great supply of aperient medicines, very rarely departing far from aloes as their staple. This is an excellent drug, and every doctor employs it. But there are two objections to the popular use of it in this way. In the first place, aloes is a very cheap drug, and there is no good reason why people who can afford no luxuries should pay ten or fifty times the fair price for a combination of, say, aloes, ginger and sugar. That is clear enough.

Drugs that may be used occasionally, but become harmful if used habitually

But a graver objection to self-drugging, even with such inherently harmless substances as aloes, and even for states of the body which require some such attention, is that every drug may be administered in a right way or in a host of wrong ways. Every textbook on therapeutics points out that aloes is an unsuitable drug to use habitually in chronic constipation. Its action is not tonic upon the flabby bowel, and it leaves the bowel with a greater tendency to constipation than ever. Therefore the wise doctor employs it only for special and exceptional purposes, not

meaning to repeat the dose, and not expecting to have to do so; and he carefully avoids it as a remedy for a condition which will be certain to recur in a few hours, for he knows that it merely relieves a symptom, and does nothing for the underlying cause. As a matter of fact, the persistent use of such a drug as aloes, or any other which increases the flow of blood through the lower portion of the alimentary canal, is very apt to lead to permanent congestion of the veins, which means the too-prevalent and tiresome malady called hæmorrhoids, or piles. That is a simple illustration of a minor evil often due to the practice we here condemn.

Legislation that seeks to protect the user of drugs

A clear remedy is a statutory requirement that the composition of all these preparations shall be stated upon the bottle or package, and such is the law in many States and was in all until 1915, when manufacturers of patent medicines, threatened with loss of monopoly should they reveal the secret of their remedies, succeeded in getting the federal law repealed. The National Pure Food Act of 1906 and subsequent revision (1915) forbade the manufacture, entry or export of any adulterated or misbranded drug in any Territory or in the District of Columbia; provided for the examination by the Bureau of Chemistry of the Department of Agriculture of all drugs there manufactured or offered for sale in unbroken packages in any State other than that of their manufacture or received from or intended for a foreign country; provided the methods of prosecuting and destroying of the goods and stipulated the penalties. Packages whose contents contain alcohol, morphine, opium, cocaine, heroin, alpha or beta eucaine, chloroform, cannabis indica, chloral, hydrate or acetanilide or any derivative, must state on the label of package the quantity or proportion thereof. The result in 1914 was the examination of a very large number of samples in interstate commerce with recommendation of 87 cases of criminal and 349 of seizure proceedings.

About 15,000 import shipments were examined by the United States Customs and over 4500 denied entry. A decision in 1914 found the legend "guaranteed under the Food and Drug Act" misleading and forbade the use of a serial number after 1916, guarantees of compliance with the law to be incorporated in invoice or bill of sale specifying the goods covered. The wide-spread disease-suggesting advertising of quack remedies was stopped, many concerns went out of business and the sale of patent medicines — especially the worst and most popular — shrank to a comparatively small figure. This act is a hopeful sign. What is now needed is a higher standard of education and direction of young people of both sexes first in the laws of life and health and thereafter in anything else that matters.

Importance of a national standard in drugs

It is absolutely imperative that there should be a uniform standard of strength and purity of medicinal products as well as uniformity in their preparation, and to attain this object the various countries have standards established by law or by professional authority, to which the drugs prepared by the pharmacists must conform. These standards are published by each nation in works known as pharmacopœias.

In the United States the first pharmacopœia was published in Philadelphia in 1778 for the use of a portion of the American army. Another was published in 1805 by the Massachusetts Medical Society. The Medical Society of the County of New York in 1818 took measures for holding a convention of delegates from various State medical societies and medical colleges which met at Washington, January 1, 1820. The action taken then resulted in the appearance the same year of the first pharmacopœia in the United States, a volume of 272 pages in Latin and English. Since the edition of 1840 the Latin has been omitted. The convention made provisions for the holding of other conventions for revision every ten years.

CONQUERING THE SUN

The Investigation of the Central Force which Sends Energy Nearly a Hundred Million Miles to the Earth

A TELESCOPE ON A CALIFORNIA MOUNTAIN TOP

THE greatest problem in astronomy is the evolution of the stars. The star nearest to us is the sun, on which depend the lives of all living things.

Nothing that goes on in the sun is unimportant to us. The cost and the quantity of all our food supplies are directly governed by the amount of sunlight and by the amount of electric force which radiate from the fiery furnace in the heavens, round which our planet spins. If it can be clearly established that there is a close connection between changes in our weather and the regular variations in the shell of the sun, then we may at last be able to foresee the recurrence of bad seasons, and make provision against them.

Extraordinary advances have been made of late in our knowledge of the sun; and it is beginning to look as though man, the conqueror of the earth, will eventually obtain sufficient knowledge of the flaming center of the solar system to make a more scientific use of its terrific forces. At present we lack the power, born of science, which would enable us to foresee what is about to happen. Nearly 93,000,000 miles away from us is a tremendous fire, in the heat and light of which we live with scarcely any more foreseeing knowledge of it than a kitten has of the kitchen stove by which it basks. It is true that we are aware of the recurrence of the four seasons, but so are the birds that migrate southward to avoid the rigor of winter. Is there anything now going on in the sun that will produce on the earth next summer disastrous weather, poor crops and scarcity of food? To this question no one is yet able to give a positive answer.

Yet much is now being done in the great solar observatories scattered about the earth to enable the man of science of the future to forecast the play of some of the vast forces in the sun. Sometimes an apparently unrelated experiment in electricity, conducted in the underground chambers of a laboratory, helps us to understand what is taking place in the star round which our life centers. For there are strange and mighty manifestations of electric energy in the sun, constituting problems that we must solve before we are able to grasp the knowledge we so ardently desire.

Owing to the generosity of a number of rich men in the United States, the best means of studying the sun are now possessed by American astronomers. Our instruments of research are the finest in the world. We have many telescopes of greater power and precision than any in actual use in Europe; and we have applied our native talent for invention in devising new and wonderful apparatus for ascertaining the actual composition of the sun.

One of the most famous of all the American observatories is that on Mount Wilson, near Los Angeles, California. Only a few years have passed since it was partly built, in circumstances of great difficulty; and the enormous telescope that completes its incomparable set of instruments was only recently installed. Erected only after a long and heart-breaking struggle against natural conditions, Mount Wilson Observatory has a story which is the latest, and one of the finest, of the true romances of science.

THE SHEER MOUNTAIN SIDE ON THE SUMMIT OF WHICH THE GREAT OBSERVATORY RESTS

The difficulties overcome in the erection of the Mount Wilson Observatory were almost inconceivable, all the building materials and instruments being hauled up the side of the mountain.

THE OBSERVATORY AT THE SUMMIT OF MOUNT WILSON IN SOUTHERN CALIFORNIA

This steel building stands nearly 6000 feet above sea-level. The great dome, 58 feet in diameter, contains the 60-inch mirror-telescope, the glass disc of which weighs one ton. To keep the temperature of the building constant the walls are of steel, two feet apart.

For some time, the astronomers of the Carnegie Institution of Washington searched the world for the site of an observatory which should command a clearer view of the sun than any then in existence. They went as far as Australia; they glanced at Arizona; and at last, in 1904, they chose a mountain in Southern California. Many things had to be avoided. Bare rocks and earth would absorb the heat of the sun and give out this heat, thus disturbing the air and interfering with telescopic work; high-lying clouds would continually obscure the view; and high winds and bad weather would be generally disastrous to the series of solar observations that was contemplated.

By placing a telescope on a height a mile or two above the sea, we do not, of course, get appreciably nearer to the sun and stars. Light travels at a speed of 186,000 miles a second; it takes about a second and a quarter to come to us from the moon, and about eight minutes to reach us from the sun. To pass, however, across the distance which separates us from the nearest star outside our solar system, it takes about four and a quarter years. And the last theory is that the light from a group of stars on the extreme edge of our universe takes 300,000 years to reach us! Standing on a mountain does as little as standing on a mole-heap to bring the stars nearer to our vision.

How the earth's atmosphere shuts us in from a trustworthy study of the sun

The trouble is the thick atmosphere that envelops our earth. We live at the bottom of a sea of air, which prevents us from viewing clearly everything beyond it. It is air that makes the stars seem to twinkle, though they are really steadily flaming suns; it is the air which absorbs many of the shorter light-waves, and gives us a wrong impression of the heavenly bodies. Especially is this so where modern photographic methods of study are employed. It is the shorter waves of light — blue, violet, ultra-violet — which affect a photographic plate, but the air stops these more than it does the long, red waves of light.

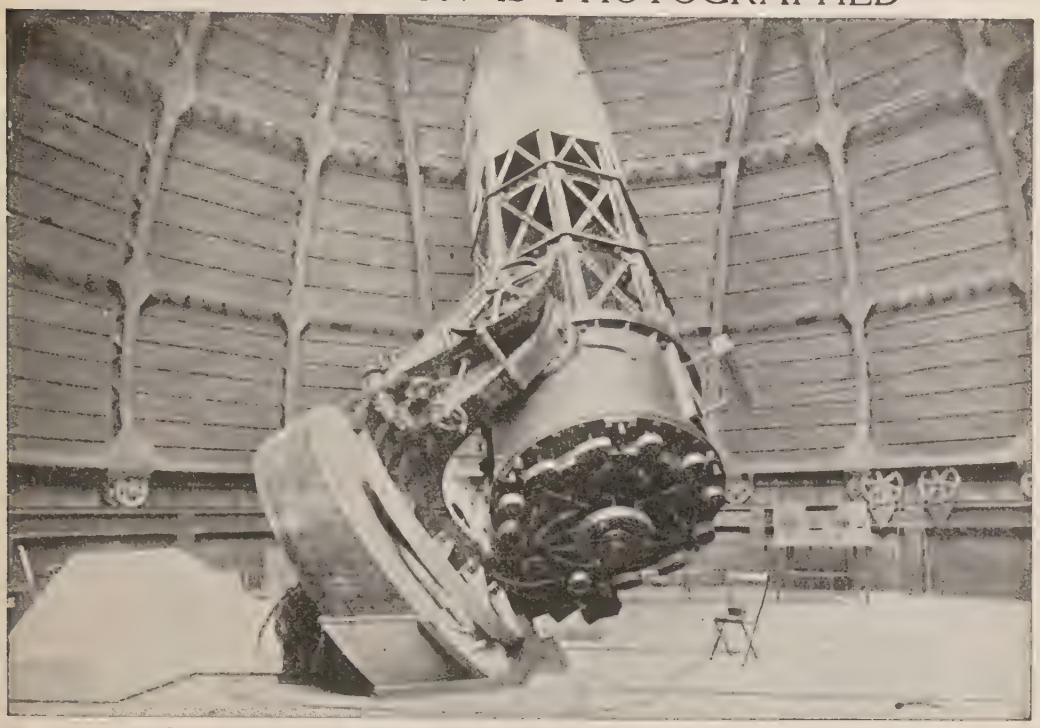
For these reasons, altitude is of great importance to astronomers. A mountain lifts them above the thick layers of air, and enables them to make more delicate and exact observations. Mount Wilson, which was selected as the site for an observatory using the largest and most powerful telescopes in the world, is one of the many heights that form the southern boundary of the Sierra Madre Range. Standing at a distance of thirty miles from the Pacific Ocean, it rises nearly 6000 feet above the green ranches and thriving towns of Southern California. The view southward reaches to Mexico, and seaward it extends to islands in the Pacific one hundred miles distant. To the north, bare vast ranges of rugged heights shut out the Mojave Desert, but near at hand the high lands are covered with pine trees, that march forward and climb to the summit of Mount Wilson. A trail, two feet in width and $9\frac{1}{4}$ miles long, connected the top of the lonely mountain with the plain beneath, when the astronomers began to build their observatory.

Fighting the battle of scientific observation against fierce onslaughts of weather

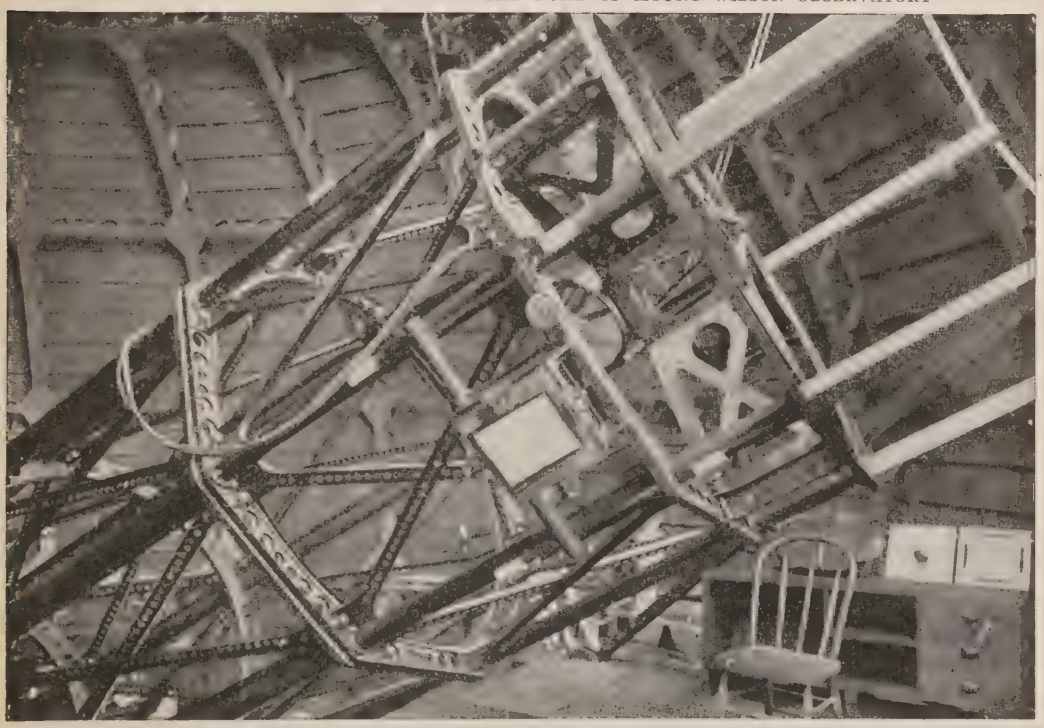
Hundreds of tons of building material had to be carried up this steep and narrow trail. Bit by bit it was packed on donkeys and mules, and sent up the mountain. It was very slow work, and very troublesome, and the trail was at last widened to admit of motor trucks being employed. The torrential rains of the rainy season brought down on the newly made road thousands of tons of earth and rock.

However, the road was remade, and by the middle of 1907 a good part of the observatory had been built. At the present time, the observatory is equipped with a great deal of apparatus which has enabled the men of science there to undertake new and extremely valuable researches. Great difficulties have been met with in connection with the newest and most powerful telescope, but these difficulties have been overcome, and all of the instruments are now in daily use. Every year sees the application of new methods of work, which result in greatly extending our knowledge of the sun and stars.

HOW THE SUN IS PHOTOGRAPHED



THE 60-INCH MIRROR-TELESCOPE IN THE DOME OF MOUNT WILSON OBSERVATORY

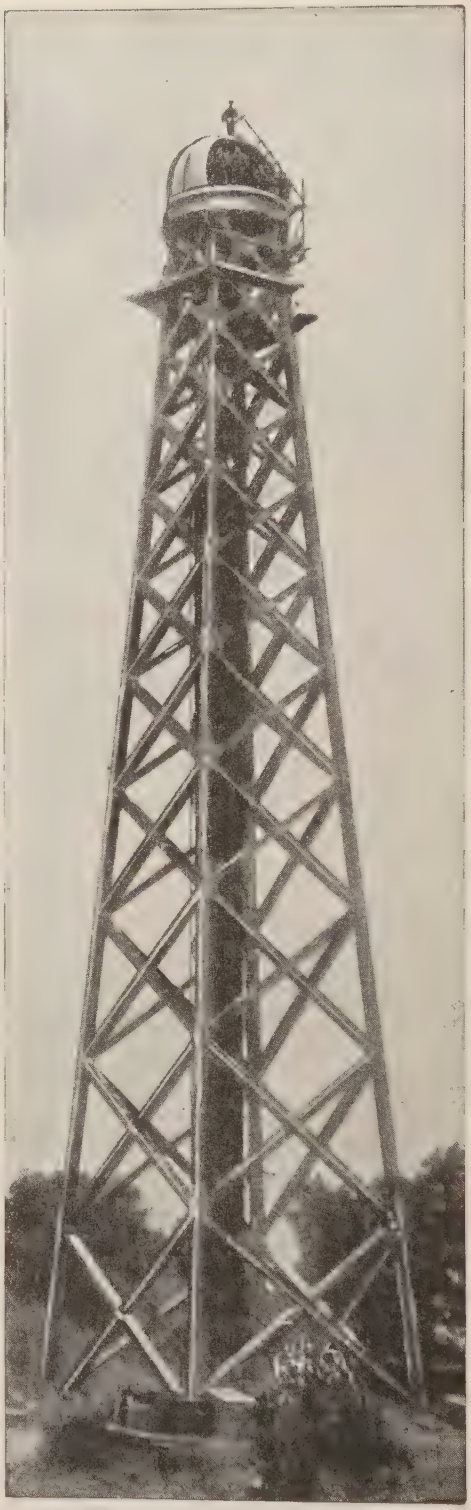


THE PHOTOGRAPHIC CAMERA IN THE FOCUS OF THE REFLECTING MIRROR

The upper picture shows the great sun telescope, and the machinery that moves it. The steel framework in the middle of the telescope supports mirrors which receive reflections from the big 60-inch mirror in the base of the telescope. These mirrors reflect light out of the frame into spectroscopes, or a photographic camera, as shown in position in the lower picture.

The climatic conditions at Mount Wilson have been found to be excellent. From April to August, fog rolls in from the ocean, and at night covers the valley. But the fog-cloud seldom rises higher than three thousand feet. Far below the observatory it stretches — a strange, dim, tumbled sea, breaking against the dark heights, and shutting out every glimpse of earth. The moonlight turns it into a floor of pearl and silver; as it lifts and scatters at daybreak, the sun colors it with lilac, rose and gold.

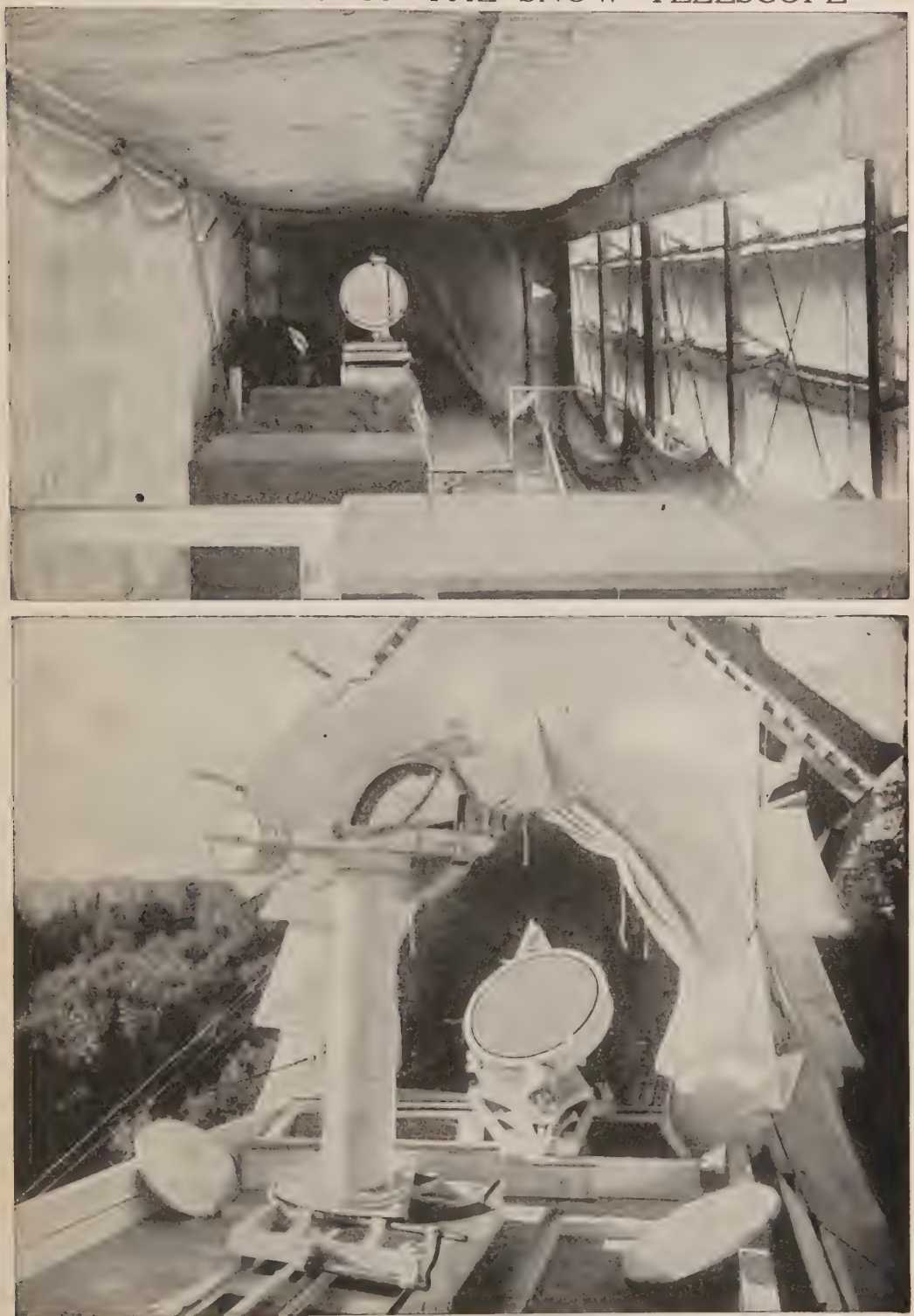
By night, the gorgeous over-arching sky is of a wonderful transparency; the stars have an unearthly brightness and a marvelous beauty. Very near they seem, even to the naked eye. By day the heavens are of a very deep blue color, and in the thin, pure air the sun puts on a dazzling brightness. During many months of the year the sunshine is continuous; and though in summer the sea-breeze blows for a part of the day, it is of very low velocity. Many of the buildings of the observatory, and particularly the towers in which instruments are fixed, are constructed of a skeleton of steel or iron. The wind blows through the structure, instead of beating against a solid wall of brick or stone. In this way vibration is much lessened; in fact, in ordinary weather it is not felt at all.



160-FOOT TOWER TELESCOPE AT THE MOUNT WILSON OBSERVATORY

The most remarkable of the towers is that which was built in 1910. It stands a hundred and sixty feet above the ground, and beneath it is a large well seventy-eight feet deep. Each of the steel members of the tower is guarded from the wind by being enclosed within an outer tube of steel, and separate foundations of concrete are made for the inner and outer portions. There are thus two towers, one within the other. On the inner tower are fixed the two mirrors and the object-glass of the telescope. The beam of light from the mirrors is sent straight down into the room at the base of the tower where the solar image is formed. To protect the beam from disturbing air-currents, it is enclosed in an iron tube, five feet and a half in diameter; the tube is lined with sheet-iron and covered by a canvas shield. In the well is a powerful spectroscope, which analyzes the light from any part of the large image of the sun. This image must not change its position during the exposure of a photograph. That is why extraordinary precautions are taken to build a telescope that shall not vibrate.

THE MIRRORS OF THE SNOW TELESCOPE



Light from the sun strikes the Snow coelostat, the lower mirror shown in the bottom picture, and is reflected to the plane mirror above it. This mirror reflects the light on to a concave mirror 145 feet away, at the end of the canvas-covered interior shown in the upper picture.

Yet an absolutely fixed telescope has a difficulty to overcome. It cannot be shifted so as to follow the movement of a heavenly body. So the instrument called a "cœlostat" is used on Mount Wilson. It consists in principle of a set of revolving mirrors; and its position can be altered so as to reflect any portion of the sky on to the lens of the fixed telescope. The mirrors stand in the opening of the dome, and they can be moved about on rails and adjusted to any position. They are twelve inches thick, and they are encased in closely fitting water-jackets, through which a stream of water is kept circulating. This is done to prevent the mirrors from getting hot. For heat makes the glass swell and disturbs the reflecting surfaces, with the result that the beam of light thrown into the telescope is so distorted that a useless image is sent down into the well.

There are two kinds of telescopes, the refracting and the reflecting telescope. An ordinary opera-glass or field-glass is a refracting telescope; so is any telescope in which a lens is used as an object-glass. The lens, which in its simplest form consists of a round piece of glass with a convex or bulging surface, bends or refracts the rays of light that pass through it. The largest practical telescope in which lenses are fitted is the Yerkes telescope, at Lake Geneva, Wisconsin. The Yerkes lens is forty inches in diameter, the front-glass is made of crown glass, the inner glass is made of flint glass, and they weigh together about five hundred pounds. The lens is of extraordinary purity and transparency; but, as it is three inches thick, it absorbs a considerable amount of light. The lens unfortunately acts as a prism, and bends the different light-waves in different directions, thus producing several colored images of one object instead of a single white image. But this is largely corrected by the use of crown and flint lenses in combination.

THE WINTER BEAUTY THAT SURROUNDS MOUNT WILSON OBSERVATORY

ONE OF THE WORLD'S LARGEST TELESCOPES

THE 36-INCH REFRACTOR, LICK OBSERVATORY, MOUNT HAMILTON, CALIFORNIA

This is the second largest refracting telescope in the world, the objective having a clear aperture of 36 inches. It has a focal length of 57 ft. 10 in. The point of suspension of the telescope tube is 36 feet from the floor. The dome, 76 ft. in diameter, like the observation platform, is moved by water power.

How Newton overcame the difficulty common to all refracting telescopes

This difficulty is the fault of all refracting telescopes; and Sir Isaac Newton, who was the first man to discover the cause of the fault, managed to get rid of it by inventing the reflecting telescope. He placed a mirror, which was formed of metal and hollow or concave in shape, at the bottom of a tube. The light fell on the highly polished surface, and from there it was reflected to a little flat mirror near the top of the tube. In the side of the tube opposite to the little mirror was a hole; in this hole the eyepiece was fixed. The beam of light fell on the large mirror; the large mirror reflected it on to the little mirror; and the little mirror transmitted it to the eyepiece. In this way the waves of light were kept from being broken up by passing through a glass lens.

Unfortunately, the little mirror which was placed in the middle of the tube cut off some of the light; and, moreover, the polished metal surfaces could not be made to reflect as much light as a piece of transparent glass will let through. So what was gained in not breaking up the light-waves was partly lost through the arrangement of the mirrors, and through the defects of the reflecting surfaces. Metal mirror-telescopes, however, can be made much more cheaply than refracting telescopes, and much fine work has been done with them.

The Earl of Rosse, for instance, constructed, in 1845, at Parsonstown, in Ireland, a mirror-telescope that had a diameter of 72 inches. It was for many years the largest in the world. The Rosse telescope consisted of an enormous tube, at the bottom of which was a huge mirror of metal. At the time it was constructed, engineering methods were inadequate to provide a proper mounting for so gigantic an instrument. It was swung in chains, and flanked by two stone walls that greatly restricted its range, yet some remarkable discoveries were made by means of it. The observer stood upon a platform far above the ground, and, looking down into the tube, saw there the image of the object. It was impossible to maintain the telescope steadily fixed for hours at a moving star; and it was impossible also to make accurate measurements with it.

The great 60-inch and 100-inch reflecting telescopes at Mount Wilson

The 60-inch reflecting telescope was fixed on Mount Wilson in 1907, the year of the great snowstorm. The huge tube is hung between the arms of a massive cast-iron fork, and pointed through an opening in the dome of the observatory. The dome is moved by electric motors, so that the opening in it also follows the course of the object which the clock-driven mirror telescope is photographing. Between the dome and the floor hangs a platform, and here the astronomer stands, looking into a second mirror, which receives the image formed by the great five-foot mirror at the end of the tube. Opposite the second mirror is a double slide plate carrier, fixed to the skeleton framework of the tube. The image is projected upon the plate and photographed. The five-foot mirror weighs one ton, and was cast by the French Plate Glass Works at St. Gobain, France—the only firm in the world with the plant for making discs of such magnitude. After being carefully tested in the workshop of the observatory, it was ground and figured by Professor G. W. Ritchey to a true paraboloidal form. The glass of these large mirrors has to be perfectly annealed, and no strain must be found in it. That is why there was so much difficulty over the $4\frac{1}{2}$-ton mirror, with a diameter of $8\frac{1}{3}$ feet, for the 100-inch telescope, similar in design, but on a much larger scale, for which Mount Wilson waited so long. Again and again the disc was cast and annealed, and again and again it broke. The disc finally adopted, however, has proved very satisfactory.

This, the greatest of all telescopes, and much the most powerful, has been completed recently. It is named for the late Mr. John D. Hooker, who provided the funds to cover the cost of the optical parts. The rest of the expense was borne by the Carnegie Institution of Washington.

THE WORLD AS SEEN FROM MOUNT WILSON

THE GLORY OF THE SUN SETTING ON THE FAR HORIZON

A STORM IN THE MOUNTAINS, AS SEEN FROM THE MOUNT WILSON OBSERVATORY

The photographic plate that is steadier than the hand and never grows tired

Many difficulties of construction had to be overcome. The long delay in securing a suitable disc for the large mirror was in some ways an advantage, for it gave opportunity for extensive studies of the best type of mountings and protection, and for investigations in many other lines.

Nearly everything is done by photography in a modern observatory. The photographic plate is steadier than the human eye, and it never grows tired. Moreover, it can record waves of light which are invisible to us, and trace the path of myriads of stars which we cannot see even through the most powerful telescope.

One of the most remarkable of all photographic instruments is that invented by Dr. George Ellery Hale, the director of the Mount Wilson Observatory. It is called a "spectroheliograph", and is used for taking photographs of the sun by the light of a single element flaming on the solar surface.

The wonderful instrument which picks out a single one of the sun's rays

As is well known, light can be broken up into a band of rainbow colors by passing it through a three-sided piece of glass. This band of colors is called a "spectrum". The curious thing about it is that it is full of dark lines as well as tints of color.

By a discovery already described in an earlier chapter, it was found out that the dark lines in the spectrum of sunlight or starlight represented the various elements which were shining in the far distant heavenly bodies. One of the lines in the spectrum representing helium, which is one of the elements into which radium decomposes, was found in the sunlight spectrum, and also in some stars, many years before the actual substance was discovered on earth. The spectroheliograph devised by Dr. Hale takes a photograph of the sun with a single light-ray proceeding from only one of the many elements which are flaming together and flooding the earth with sunshine. In this way it is possible to obtain a large and exact photograph of, for instance, all the calcium which is blazing on the surface of the sun. Or the calcium-ray can be shut out, and only the ray produced by the iron clouds in the sun can be photographed.

This is how it is done. The large solar image from the 60-inch telescope or one of the tower telescopes is made to move across a narrow slit. Behind the slit is a prism of glass, which breaks the light up into a long band of spectrum colors. The spectrum is thrown on to the lens of a camera tube. Behind the lens is another slit, and behind the slit is a photographic plate mounted on a carriage which runs on rails, and is timed to move exactly at the same rate as that at which the solar image from the telescope moves across the first slit.

How a photograph of the sun may be taken to show only one of its elements

The delicacy of the operation is mainly a matter of adjusting mirrors and lenses so that only a certain line in the twenty thousand lines of the spectrum enters through the photographic slit. This adjustment is, of course, made before the solar image and the photographic plate are set in motion.

Let us suppose that Dr. Hale wishes to take a photograph of the sun by the light of the flaming calcium in the sun. In the extreme violet region of the spectrum there are two broad, dark bands known as *H* and *K*. These represent calcium, the metallic base of lime.

The telescope is directed at the sun, and the image formed is thrown on a prism, and there broken into a band of color, which is reflected on the lens of the camera, and from there thrown on the screen in the middle of which is a slit. Then either the telescope or the prism of glass is moved until one of the two lines *H* and *K* falls exactly through the slit on to the photographic plate—all the rest of the lines and colors being blocked out by the screen. When this has been done the double movement of the solar image and the photographic plate is started.

THE SEAS OF FOG THAT LIE ABOVE THE CLOUDS

THE SUNNY SIDE OF FOG — A BANK OF MIST VIEWED FROM MOUNT WILSON

THE DENSE CLOUDS OF FOG ABOVE WHICH MOUNT WILSON TOWERS IN SUNLIGHT

The result is that every wave of light created by the glowing calcium clouds in the sun strikes against the photographic plate as the solar image is slowly moved across the slit of the prism.

To put it roughly and briefly, the sunlight is broken up and then filtered, and only that fragment which represents some special element is allowed to pass through the filter and record itself upon the plate. Thus is obtained a picture of the sun lighted by the rays from a single element glowing there.

By means of the spectroheliograph, astronomers are now able to analyze the sun more easily and exactly than a chemist could analyze a furnace a few years ago. For Dr. Hale has now improved his wonderful instrument, so that it gives a photograph of vapors of a single element lying at a low level on the sun, light-waves from the same vapors at a high level being blocked out with the rest of the spectrum. Or those at high levels can be photographed alone. Thus the true structures of the solar phenomena are now being discerned; and some of the most fundamental problems of the universe are in a way to be solved at the Mount Wilson Observatory.

Differences of temperature on the surface of the sun can now be distinguished by means of the spectroheliograph; and this new knowledge has proved of great value in examining the vapors associated with sun-spots. Spectroheliographs are now used daily in England, France, India, Sicily, Spain and the United States. The observatories in which they are employed are connected together in an Astronomical Union, which is making a combined attack on the sun from different parts of the world. In time, very important additions to our knowledge of solar phenomena will be obtained; and perhaps we shall then be able to forecast to some extent the play of some of the forces in the sun which vitally affect the life of everything on our earth.

Much continuous daily research in all the solar observatories is still required. For instance, there are twenty thousand lines in the spectrum of sunlight, and hundreds of these lines need to be examined over and over again with the spectroheliograph before we obtain separate photographs of the substances of the sun.

The inconceivable forces set in play on the surface of the sun

We already know a great deal about the calcium, hydrogen and iron glowing in vapor at various levels above the solar shell. It is possible that the enormous heat of the sun may produce substances which we cannot imitate in our laboratories, but in various ways we are gradually coming to understand the theory of what takes place in the gigantic furnace of the sun. Possibly we shall never be able to reproduce in any experiment all the conditions of solar heat.

The forces set in play merely on the outer portions of the sun's globe are simply inconceivable. Perhaps the explosion of cordite, when one of the $13\frac{1}{2}$-inch guns of a battleship is fired, is as striking an example of the force of ignited gases as we are familiar with. Now, suppose that every foot of space in the State of New York were covered with such guns, all pointed upward, and all being discharged at once. The result would compare with what is going on in the sun as a boy's popgun compares with the big guns of the battleship.

Has a spot on the sun anything to do with the price of wheat?

One of the problems in regard to the sun which the astronomers are tackling is that relating to variations of heat. We can take it for granted that the sun will continue to radiate heat for many centuries to come at practically the present average rate. But do we know that the rate is absolutely constant? May not fluctuations occur of sufficient magnitude to affect our climate, and to be reflected in change in the quantity of crops and the price of wheat?

Until a short time ago this question had been tested in only the roughest way. It was known that sun-spots passed through a regular cycle of change, occupying about eleven years. A curve was accordingly

drawn, showing the varying number of sun-spots, and this curve was compared with the curve representing the varying price of wheat. As the two were thought to show some correspondence in form, it was held that the price of wheat was determined by the solar activity as measured by the number of spots.

The whole question, however, is still in its early stages, and little has been learned yet which is absolutely definite and trustworthy. Work of special importance is being carried on by Dr. Abbot of the Smithsonian Astrophysical Observatory with very ingenious apparatus. At regular intervals the image of the sun is split up into the band of colors of the spectrum, and this band of colors is made to move slowly over an instrument which can record the heat of a candle at the distance of a mile or more. In other words, the instrument measures a rise in temperature of less than one millionth of a degree. It is called a "bolometer," and we have already described it.

The measurements were begun several years ago, and important changes in the solar radiation have been detected. Some time may elapse, however, before we can be sure that we are in a way to discover that law of the variations of the heat of the sun which will enable mankind to become more the master of its immediate fate than it is now.

The extraordinary changes that may take place in the inside of the sun

From the results obtained it seems likely that the solar heat temporarily undergoes actual change which is not to be ascribed to any modification of our own atmosphere.

Photographs taken of the sun's surface by means of the spectroheliograph seem to show that these changes of heat are brought about by violent currents which convey large quantities of heat from the depths of the sun to the exterior. But the problem is not simple. For the increased radiation produced by great solar activity may quickly be checked by the diffusion, through the atmosphere of the sun, of the materials thrown upward by the violent eruptions. Simultaneous observations at several widely separated mountain ranges are greatly to be desired. By this means it would be possible to ascertain if local changes in the earth's atmosphere are in any way concerned in the apparent solar changes.

Continuous study without weather interruption of variations of solar heat

Moreover, the work should go on without the interruptions caused by the rainy season. For example, when the rains begin to fall at Mount Wilson, there is a dry season at the solar observatory at Kodaikanal, in South India, which has an elevation of 7000 feet. So astronomers of the two observatories could coöperate in studying the variations of solar heat, special regard being given to a standardization of the bolometers and other instruments of measurement. An Australian station would also help greatly in accomplishing very important results, and it is hoped that provision may soon be made to establish such a station.

It might be thought that if there are real fluctuations in the sun's heat, which cause marked changes in the temperature of the earth, the effect would be obvious and easily detected. But as a matter of fact the atmosphere and the weather of our earth form a very complicated mass of phenomena, in which the sun's varying heat is only one factor. The rotation of the earth, and the complicated movements of its atmosphere produce effects of a very complex kind. These effects have to be traced and disentangled before we can clearly discern the part played by fluctuations in the solar heat on our weather. Studies of the solar radiation have been undertaken by the Astronomical Union, and coöperation in the science of weather has been started by some of the weather bureaus. Thus there are many investigators now engaged in an exhaustive study of one of the most practical and important points in astronomy. The work, however, is barely begun. It must be continued for many years before it can have a direct effect upon the lives of the whole of the human race.

A MERCATOR MAP OF THE WORLD, SHOWING THE CENTRAL POSITION OF THE PANAMA CANAL

THIS MAP, DRAWN WITH PANAMA AS A CENTER, SUGGESTS THE COMMERCIAL FACILITIES AFFORDED BY THE CANAL TO THE UNITED STATES

SHORTENED TRADE ROUTES

The Effects of the Panama Canal
from a Commercial Point of View

THE GREAT GAIN BY AMERICA

A GLANCE at a Mercator map of the world — or, better, a survey of the world's land and sea spaces as shown more accurately on the too much neglected "globe" — will show that, when man learned to navigate the great waters, the world presented two small but very effective land barriers to the sea-voyager. We see the great mainlands of Asia and Africa linked by the tiny Isthmus of Suez, and we see the two tapering Americas made one by the narrow neck of Panama. It was as though nature left man two problems to solve in order to remind him of the kind and magnitude of the mighty works she herself accomplishes so easily.

The first named of the two problems was attacked thousands of years ago by the ancient Egyptians. True it is that they never attempted to make a direct cut through the neck of land, but the waters of the Nile formed a natural base from which to make a connection between the Mediterranean and the Red Sea. The first of such canals known is that of the time of Seti I (1380 B.C.), and it is pictured on the walls of the Temple of Karnak. Other and more ambitious attempts — some of them costing tens of thousands of lives — followed; and in 1861 French engineers were actually able to utilize part of the work of the ancients in constructing the fresh-water canal from Cairo to the Red Sea.

But for the Turks there might have been a Suez Canal proper many centuries ago. The design of a direct cut from the Mediterranean was conceived by the Venetians, but their negotiations with Egypt ended with the conquest of the land of the Pharaohs by the Turks.

No more was done until the middle of the nineteenth century, although Napoleon was fascinated by the subject in 1798, and caused a survey to be made — unfortunately by an engineer who was deceived as to the respective levels of the Mediterranean and the Red Sea.

As late as 1823 the only passenger route to India was via the Cape of Good Hope. An Indian merchant could not obtain communication with his customer or agent in the East under about six months. Less than a century ago trade with India was thus a matter of extreme difficulty. In 1840 an overland route to India was devised, which, although very expensive and cumbersome, was a great assistance to trade and communication. A ship sailed to Alexandria, and from thence her mails and passengers went overland to Suez. At Suez they were picked up by another vessel, and taken to Bombay or Calcutta via Aden. Much time was thus saved and much trade thus created, but the process was a clumsy one.

Suez Canal projects were revived in 1846, when French engineers reported in favor of a route via Cairo. The origin of these projects, which led directly to the great work of De Lesseps at Suez and Panama, is of much interest. It began with the Comte de Saint-Simon, the French socialist and dreamer of great dreams, whose scheme for the regeneration of the world included a Panama Canal and a canal connecting Madrid with the sea. Prosper Enfantin, one of his chief disciples, organized the society which made the Suez surveys of 1846, and Ferdinand de Lesseps gained his idea from the Saint-Simonists.

It is unnecessary to trace the history of the Suez Canal undertaking in detail, but it is of interest to observe that its progress was marked by a curious illustration of the worthlessness of cheap or forced labor. At first forced labor was supplied to De Lesseps by Said Pasha. When this evil system was ended by political action, and the company compelled to dispense with it, greater attention was given to mechanical labor-saving appliances, and greater progress was made. The first capital was subscribed in 1858, construction commenced in 1859, and the formal opening took place in 1869. Thus this great highway is little more than half a century old.

In 1875 Lord Beaconsfield wisely bought for the British government the khedive's holding of Suez Canal stock — about one-half the capital of the concern — for only £4,000,000. The stock is now worth over £30,000,000 and yields £1,000,000 a year to the British government, or 25 per cent on the investment. It is a wonderful development in view of the fact that, more than halfway through the work, De Lesseps had to issue canal stock at a heavy discount in order to obtain more capital, and had even then to devise a lottery in connection with the discounted issue to attract applicants.

This first great emendation of the world's geography made an enormous difference to European trade with the Orient and with Australasia. Ships gained a straight course through to the lands of the Southern Cross, and the great markets of the Near East and Far East were developed as never before. It is necessary to remember the recent date of these developments to understand the commercial history of the world in the last generation, and to comprehend that we are just beginning to develop the world as an estate.

Important as was the Suez Canal to Europe and the world at large, the work which has more recently been completed at Panama far transcends it in magnitude and probable effect upon commerce. It is as yet little realized what changes will be wrought by the great Central American enterprise — the greatest engineering work the world has ever seen.

The idea of cutting through the Isthmus of Panama naturally suggested itself soon after the first exploration of Central America. It was in 1500 that Balboa, the Spaniard, first landed on the Isthmus and in 1513 he crossed the neck on foot in twenty-three days, discovered the Pacific Ocean, and "took possession" of it in the name of the king of Spain. The Spaniards formed highways paved with stone across the Isthmus, which can be traced in places today; and Panama, founded in 1517, became a rich and famous city, for through it passed all the commerce from Peru to Spain. The spoils of the Incas traversed those stone highways.

The first conception of the Panama Canal is said to have originated in those early days with one of Balboa's followers, a Spaniard named Saavedra, who made plans for submission to Charles V of Spain. The project was found impracticable, and another plan made in the time of Philip II was also rejected, and it is certain that the science of that day would have been unequal to the task, even had it been undertaken.

In 1825 the great liberator Bolivar, then president of New Granada, gave a concession to Baron Thierry to construct an Isthmian Canal, but capital was not forthcoming for the enterprise. In 1838 a French company obtained a concession to make either a road, railway or canal, but again there was failure to start work.

The settlement of the northwest boundary question, by which the United States came to possess Oregon, and the Mexican War, which added California to the Union, naturally turned the eyes of the American people to the great problem of the Isthmus. The overland route to the Pacific Coast was difficult and dangerous, and the main current of immigration was deflected via Cape Horn. In order to make the newly acquired territory more accessible, lines of steamships from New York to the Isthmus, and from the Isthmus to California and Oregon, were established by Americans, with a view to the building of a railway across the Isthmus as a connecting link, from which they would derive the greater part of their profits.

In 1848 an American firm secured a concession for the railway from the state of New Granada, and entered upon the construction of the Panama Railroad. After great difficulties, both financial and physical, the road from Aspinwall — now Colon — to Panama was opened in 1855. The Panama Railroad Company secured great advantages, including the exclusive right to construct a railway or canal within a certain area, which gave the concern complete control of the Panama route. Subsequent modification gave this control for ninety-nine years from 1867. In 1848 gold was discovered in California, and the success of the Panama Railroad Company was assured. The success of the railroad and the enormous difficulty of canal construction led to the neglect of the company's canal concession.

In 1850 the important Clayton-Bulwer treaty was entered into between Great Britain and the United States. This treaty recognized the vital importance to British interests of any project for cutting the Isthmus. It was abrogated in 1901, when the Hay-Pauncefote treaty gave the United States a perfectly free hand, and Britain ruled herself out. Owning most of the world's ships, and herself a great American power, Great Britain formally retired from any active participation in this mighty project. Some of the chief West Indian Islands, part of the north of South America, the great Dominion of Canada and, above all, half the world's shipping is British. The British Empire had thus a definite *locus standi* when in 1901 it renounced participation in Panama Canal affairs.

To return to the situation after the signing of the Clayton-Bulwer treaty, the success of the Panama railway did not blind the American government to the need for a canal; and in 1869 President Grant appointed an Interoceanic Canal Commission. In 1870 a treaty was made between the United States and Colombia, providing that the work should be done if a satisfactory plan could be made. The Panama Railroad Company's neglected concession was inspected, and many other less favorable routes were also considered. The commission finally decided on the Nicaraguan route, always the greatest rival of the Panama plan. Their report was made in 1876, but nothing was done, and the matter was dropped.

Then De Lesseps took up the running, and for many years French enterprise and capital and life were poured out — largely to waste — in Central America.

A French emissary secured a concession from Colombia for the construction of a canal in 1878, and the Panama Canal Company was formed. The company obtained power to make the canal in any part of the Isthmus, subject to its coming to terms with the Panama Railroad Company in respect of its prior concession if the latter's territory was invaded. The new company solved this difficulty by buying up the Panama Railroad at the extravagant price of some $25,500,000. It was decided to construct a sea-level canal, without locks, and the cost was estimated at under $200,000,000. The work was to be done in twelve years, which would have meant completion in 1890. A preliminary capital of $60,000,000 was promptly subscribed, for the success of Suez was remembered.

Misfortune, and worse, dogged the steps of the enterprise, and by 1889 — when the canal was to have been nearly completed — the company was in bankruptcy, and the work brought to a standstill. Two years before, the sea-level plan had been abandoned and a scheme of locks substituted.

Private enterprise, which had carried through the Suez work — although with great difficulty and with much waste of money — had completely failed. The management was not only extravagant, but corrupt, and a financial scandal of the first magnitude ruined thousands of investors, and caused grievous loss to hundreds of thousands. The sum of $262,000,000 had been spent, and in eight and a half years less than a quarter of the canal had been constructed.

A new Panama Canal Company was formed in 1894, which took over the assets of the old one, and, after surveys, resumed the work again, and with excellent engineers.

But the undertaking was too big to be intrusted to private speculation, and it became evident that the undertaking could never command sufficient capital to complete its gigantic task.

The United States government, after much vacillation, finally took energetic action. In 1902 an Act of Congress was passed, authorizing the president of the United States to acquire the assets and rights of the new Panama Canal Company at a cost not exceeding $40,000,000, and to secure from the republic of Colombia the perpetual control of a strip of land across the Isthmus, containing the undertaking, not less than six miles wide, carrying the right to "maintain, operate, and protect" the canal. The act authorized the president, if he failed in these negotiations, to proceed with the alternative Nicaraguan route.

The United States government early came to terms with the French new Panama Canal Company, who agreed to take the $40,000,000. The republic of Colombia was not so amenable, and in 1903 rejected the terms of the American government.

However, a convenient insurrection broke out in the small state of Panama, one of the provinces of the republic of Colombia. This revolt had the moral support of President Roosevelt, and Colombia was, of course, helpless. America sent warships to Panama, and Colombia was not able to suppress the insurrection in her dominions. A republic of Panama was promptly formed — total population then about 300,000 men, women and children — and with it the United States government made the bargain which the republic of Colombia had rejected.

The resulting geographical arrangement is peculiar. Colombia has lost one of her provinces, Panama; and Panama is an independent republic. Through this tiny republic there runs a strip of land, ten miles wide, containing the canal works, and within this strip the United States is lord and master. Even that part of the city of Panama which constitutes the port is within the canal zone, and therefore foreign to the republic of Panama.

The prompt and vigorous action by which President Roosevelt thus made certain the building of the Panama Canal has been much debated. On the one hand, it has been held to be an instance of the bullying of a small power by a great one. On the other hand, it has been urged, with much force, that Colombia was asking for more than a fair *quid pro quo*. She was entitled to capitalize her own strategic geographical position. But she had no right to block the progress of civilization by asking for more than a fair price. The whole matter has now been happily settled by a treaty between Colombia and the United States, ratified in 1921. By the terms of this treaty the United States is ultimately to pay Colombia the sum of $25,000,000.

Another controversy born of the building of the canal has, perhaps, not yet been concluded. The Panama Canal Act of August 24, 1912, exempted American coastwise shipping from the payment of the canal tolls. This provision was held by the British and by many Americans to be in conflict with the terms of the Hay-Pauncefote treaty of 1901, which provided that: "The canal shall be free and open to the vessels of commerce and of war of all nations observing these rules on terms of entire equality, so that there shall be no discrimination against any such nation, or its citizens or subjects, in respect of the conditions or charges of such traffic, or otherwise." At the instance of President Wilson, who urged that our national honor was involved, the exemption given American coastwise shipping by the Act of 1912 was repealed in 1914, but the terms of the statute which effected the repeal were so phrased as to make it clear that the United States did not waive any of its rights to control the canal, including rights to levy discriminatory tolls.

At first thought it would seem clear that if the United States is to abide honorably by the terms of the treaty of 1901 it cannot give to American ships any favors in respect of the use of the Panama Canal which it does not grant on equal terms to the vessels of other countries.

But the matter is by no means so simple. The United States, like most other countries (not including Great Britain), reserves its *coastwise shipping* wholly to vessels under the American flag. If American vessels carrying goods from Atlantic to Pacific ports of the United States or vice versa were exempted from the canal tolls, it is by no means absolutely clear that this would constitute a discrimination against British or other foreign vessels. Such vessels cannot, on any terms, engage in the American coastwise traffic. Consequently it may be held, with some plausibility, that any special favors given to such traffic do not discriminate against other countries. Of course, if our policy should be to adjust tolls to the cost of operating and maintaining the canal, the exemption of American coastwise vessels would make the tolls imposed upon foreign vessels, as well as upon American vessels bound from the ports of one country to those of another, higher than they otherwise would be. From the point of view of our own economic interests, the values involved are relatively small, not large enough to justify an action which might be construed, even if unfairly, as a violation of a treaty obligation.

The formal transfer of the French undertaking to the United States government was made on May 4, 1904, and the great work was at last in the hands of persons strong enough to carry it through. The course taken by the American administrators was in striking contrast to that pursued by the French speculators. The peculation and corruption of the old régime disappeared. The first few years of the American operations were wisely devoted chiefly to making plans and putting the house in order.

The Panama Railroad was reconstructed and double-tracked. Proper houses were erected for the army of workmen needed, for it was realized that everything depended upon efficient labor. Above all, sanitation was perfected, and the two dread diseases, yellow fever and malaria, tackled and beaten. What had been a fever-infested jungle was transformed into a sanitary and healthy district, in which workmen would live and work healthily and efficiently. The mosquito — two varieties of which respectively carry yellow fever and malaria — was banished from the Canal Zone, by draining and drying up the pools in which alone it can breed. Where the French and their men sickened and died, the Americans and their men now live in immunity. Yellow fever is unknown in the canal works, and the Canal Zone death-rate has fallen to a figure that would be creditable to a temperate climate. In two and a half years the civilization of Panama was advanced from where it stood in the sixteenth century to a twentieth century standard. It has been a magnificent lesson in the proper way to organize industry and commerce on a large scale.

It may be truly said that the American conquest of disease at Panama is fully of as much importance as the conquest of mighty masses of land and water. Without the medical and sanitary victory, the canal might never have been completed, but that is only one part of the great service which has been rendered to trade and industry. Insanitary conditions and deadly insects had much to do with beating the French, just as they had much to do with the decline of ancient Rome and ancient Greece. By making civilized life possible at Panama, the Americans have opened up new opportunities for large and important sections of the world. If white men can live and work and trade in Central America, why not in other tropical regions? It may prove to be the case that white colonies may come to live and flourish at the tropics, and, if so, the wealth and prosperity of the world as a whole will be greatly advanced by the leading races of mankind in developing latitudes where there is a continuous harvest throughout the year.

The official report of the Isthmian Canal Commission for 1911 shows that in that year the Panama Canal Zone had a population of over eighty-eight thousand, and that the death-rate was a fraction over fifteen per thousand, which is very nearly the death-rate of Great Britain.

For the combined population of the cities of Panama, Colon and the Canal Zone, the death-rate in 1911 was twenty-two per thousand. To show the progress that had been made, it may be mentioned that in 1907 the corresponding death-rate was forty-two per thousand. If we take the employees of the canal works alone, the death-rate had fallen from nearly forty per thousand in 1907 to a fraction over eleven per thousand in 1911, and to nine and a half per thousand in 1920.

It is significant that the United States succeeded where the French had failed because it saw to it that the fundamental causes of the French failure were eliminated. The first of these causes was the inadequate appreciation of the importance of sanitation. The second was the waste and corruption which attended the use of funds raised in France to build the canal. Money that should have gone toward construction was used up in bribes to the press and to men prominent in public life.

Not only did the United States government begin by putting sanitation first, but it also made a remarkable record by bringing the construction of this gigantic work to a completion at a cost which was trifling as compared with the nature of the engineering problems encountered, and as compared, moreover, with the value of the results. The canal had cost when completed $375,000,000. But this includes the $40,000,000 paid to the French company for its rights and properties, $10,000,000 paid to Panama, $20,000,000 for sanitation, and over $7,000,000 for the civil administration of the Canal Zone. This is a small price to pay for a work which means so much for America, whether in peace or in war. The results achieved by America by the expenditure of this sum in Central America will fructify a hundredfold for American interests. In peace, our commerce and our mercantile marine will be stimulated and developed; in war, the possession of the canal will be a magnificent advantage, rendering our navy of twice its present value by making the Atlantic and Pacific seaboards practically one.

Let us now consider the effect upon commerce of the cutting of the Isthmus of Panama. The voyage from New York to Japan is shortened by 3700 miles. Formerly a vessel sailing from New York for the Far East used the Suez Canal. By the Panama Canal the route from New York is westward instead of eastward. Or consider the effect upon the voyage from New York to Sydney. As things were, a ship made the voyage eastward round the Cape of Good Hope, a journey of nearly 14,000 miles. With the Panama Canal available, the voyage is westward, and is shortened to about 10,000 miles, saving about 4000 miles.

These instances help us to realize that America is a greater gainer by the canal than Great Britain or any other European country. We may put it that the opening of the Panama Canal means for the Atlantic seaboard of the United States a gain in relation to the Orient and Australasia in which Europe shares little or nothing, and which therefore is a relative gain for the United States.

It should be remembered that what is true of New York is true also of the Canadian Atlantic ports and of the West Indies. Indeed, no part of the world stands to gain more by the opening of the Panama route than the West Indian islands. These islands are likely to take on a new prosperity and to gain tremendously in importance, whether for commercial or for strategical purposes.

America's central position in world trade had been greatly furthered by the joining of her two important seaboards. Formerly the voyage from New York to California meant the long route round Cape Horn. Utilizing the canal, a ship leaving New York for any port on the west coast of North America has its voyage shortened by 8400 miles. The maximum possible saving for any vessel is 10,500 nautical miles, the distance by water around South America from the eastern to the western terminus of the canal. This maximum is merely a theoretical maximum or limit, for the actual trade routes that ships used did not, of course, hug the shore so closely.

The saving is better measured in terms of economy of time. The largest use of the canal has been on the part of vessels engaged in the coastwise trade of the United States. Each of these vessels has saved close to 8000 miles on this trip. It must be remembered, however, that many of their trips would not have been undertaken if they had had to round the Horn. The goods would have been sent by rail across the continent, or via the Panama Railroad, or possibly across the Isthmus of Tehuantepec — or not sent at all!

The Panama Canal makes San Francisco nearer to Liverpool by 5666 miles, a saving of nearly two-fifths. From San Francisco to Rio de Janeiro the saving is less than 1000 miles, but from San Francisco to Freetown, on the West Coast of middle Africa, the canal route of 7277 miles is less than two-thirds of the distance by the Strait of Magellan. New York is 3768 miles nearer Yokohama, but is only 41 miles nearer Manila by Panama than by Suez.

The accompanying tables, drawn from official sources, give further comparisons of distances which the reader will find interesting. Possibly the most significant table is that which shows the number of days saved for vessels of ten knots per hour. The number of days saved for slower vessels is proportionately more, and for faster vessels proportionately less.

HOW PANAMA CANAL REDUCES DISTANCE (IN NAUTICAL MILES) BETWEEN ATLANTIC AND PACIFIC PORTS

To	From				
	Boston	New York	Norfolk	Port Tampa	New Orleans
Sitka	7,676	7,873	8,020	8,748	8,868
Portland, Oregon	7,676	7,873	8,020	8,748	8,868
San Francisco	7,676	7,873	8,020	8,748	8,868
San Diego	7,686	7,883	8,030	8,758	8,878
Honolulu	6,413	6,610	6,757	7,485	7,605
Guayaquil	7,208	7,405	7,552	8,280	8,400
Callao	6,053	6,250	6,397	7,125	7,245
Valparaiso	3,550	3,747	3,894	4 622	4,742
Yokohama	3,435	3,768	4,116	5,585	5,705
Shanghai	1,543	1,876	2,224	3,693	3,813
Hongkong	351 *	18 *	330	1,799	1,919
Manila	202 *	41	389	1,858	1,978
Melbourne	2,507	2,770	3,024	4,162	4,282

* Distance less via Suez.

DAYS SAVED BY 10-KNOT VESSELS BY USING THE PANAMA CANAL ROUTE BETWEEN ATLANTIC AND PACIFIC PORTS

To	From				
	New York	Charleston	Port Tampa	New Orleans	Galveston
Sitka	32.3	33.8	35.9	36.4	36.7
Portland, Ore.	32.3	33.8	35.9	36.4	36.7
San Francisco	32.3	33.8	35.9	36.4	36.7
San Diego	32.3	33.8	35.9	36.4	36.7
Honolulu	27.0	28.5	30.7	31.2	31.5
Guayaquil	30.3	31.8	34.0	34.5	34.8
Callao	25.5	27.0	29.2	29.7	30.0
Valparaiso	15.1	16.6	18.7	19.2	19.5
Yokohama	15.2	18.5	22.8	23.3	23.6
Shanghai	7.3	10.7	14.8	15.4	15.7
Hongkong		2.8	7.0	7.5	7.8
Manila		3.0	7.2	7.7	8.0
Melbourne	11.0	13.5	16.8	17.3	17.6

The significance of these economies may be inferred from the fact that the per diem cost of operating a freighter runs from several hundred to over a thousand dollars, depending upon its size and speed. In addition, the saving of time reduces interest and depreciation on the cargo.

Not all costs, however, can be reckoned in terms of distance or time. Other conditions may sometimes determine what route a vessel will choose. Fueling costs, weather conditions, and the like, may be the deciding factors. The governor of the Panama Canal, in a recent report, explains that the two great trades in which the canal is in direct competition with other water routes are those between Europe and Australasia, and between the Atlantic Coast of the United States and the Far East. A ship from Great Britain with cargo for Australasia might go through Suez or around the Cape of Good Hope or through the Panama Canal without losing or gaining much time as compared with the alternative routes. For the homeward journey it would have the same choice and, in addition, a possible route through the Strait of Magellan and up the eastern coast of South America. Frequently the deciding factors are fueling costs and the possibilities of picking up additional traffic along the way.

HOW THE PANAMA CANAL REDUCES DISTANCE AND TIME (Vessels of 10 knots) FROM EUROPEAN PORTS TO THE PACIFIC

To	From									
	Liverpool		*Hamburg*		*Antwerp*		*Bordeaux*		*Gibraltar*	
	Distance Saved	Days Saved	Distance Saved	Days Saved	Distance Saved	Days Saved	Distance Saved	Days Saved	Distance Saved	Days Saved
Sitka	5,666	23.1	5,528	22.5	5,528	22.5	5,376	21.9	4,950	20.1
Portland, Ore.	5,666	23.1	5,528	22.5	5,528	22.5	5,376	21.9	4,950	20.1
San Francisco	5,666	23.1	5,528	22.5	5,528	22.5	5,376	21.9	4,950	20.1
San Diego	5,676	23.1	5,538	22.5	5,538	22.5	5,386	21.9	4,960	20.1
Honolulu	4,403	17.8	4,265	17.2	4,265	17.2	4,113	16.6	3,687	14.8
Guayaquil	5,198	21.1	5,060	20.6	5,060	20.6	4,908	19.9	4,482	18.2
Callao	4,043	16.3	3,905	15.8	3,905	15.8	3,753	15.1	3,327	13.3
Valparaiso	1,540	5.9	1,402	5.3	1,402	5.3	1,250	4.7	824	2.9

Thus, it will often be profitable for a vessel to go out through one canal and return through the other. By going around the Cape of Good Hope or through the Strait of Magellan the vessel saves heavy canal tolls.

Manila and other points in the Far East south of Japan are practically equidistant from New York via Suez or Panama. In practice, however, it has been found that most of our vessels have gone from the United States to the Far East via the Panama Canal, although the return voyage is governed by cargo offerings.

In commerce, relative advantage means a great deal; and it is no little thing for America that she has regained the relative advantage which the Suez Canal gave to Europe, while securing further relative advantages in other directions.

If we consider the present position of Liverpool and New York in relation to San Francisco, we see that when in each case the voyage had to be made via Cape Horn, Liverpool was almost as near to San Francisco as was New York. By the Panama Canal, however, New York is immediately brought 2750 miles nearer than Liverpool to San Francisco — a position very near equality is suddenly changed into a great relative advantage for New York.

Unfortunately for the immediate success of the Panama Canal, its opening and the outbreak of the Great War were practically simultaneous. By curtailing ocean-borne commerce the war limited its usefulness, and this must be taken into account in interpreting the statistics given in the following table. There has been a growth in traffic since the war, and, despite the fact that 1921 was marked by world-wide commercial depression, it was larger that year than ever before. In 1921 45 per cent of the traffic through the canal was carried by American ships, 32 by British ships, 7 by Japanese ships, and a little less than 6 by Norwegian. In the first ten years of the operation of the canal 25,032 ships passed through it, carrying 107,000,000 tons of cargo, and paying nearly $98,000,000 in tolls.

THE PANAMA CANAL TRAFFIC

Year	Ships	Net Tonnage	Tons of Cargo
1915 *	1,072	3,772,167	4,926,145
1916 **	760	2,385,284	3,063,371
1917	1,806	5,817,607	7,083,045
1918	2,068	6,584,073	7,533,031
1919	2,028	6,145,094	6,946,540
1920	2,478	8,546,044	9,374,499
1921	2,892	11,415,876	11,599,214
1922	2,736	11,417,000	10,885,000
1923	3,967	18,606,000	19,568,000
1924	5,230	26,149,000	26,995,000

* The canal was opened to commercial traffic August 15, 1914.

** The canal was closed to traffic from September 18, 1915, to April 15, 1916.